

FINAL REPORT - Part IV

Contract NAS 9-13870

with

The Methodist Hospital
Houston, Texas

AUTOMATED ELECTROENCEPHALOGRAPHY SYSTEM

AND

ELECTROENCEPHALOGRAPHIC CORRELATES OF SPACE MOTION SICKNESS

Principal Investigator: James D. Frost, Jr., M.D.

November 18, 1977

CONTENTS

	page
SECTION 4. SIGNIFICANCE OF EEG CHANGES ASSOCIATED WITH SPACE FLIGHT: COMPARATIVE STUDIES OF NORMAL INDIVIDUALS AND SUBJECTS UNDERGOING PROLONGED BED REST	1
4.1. SUMMARY	1
4.2. INTRODUCTION	1
4.3. METHODS	2
4.3.1. EEG Variability in Normal Control Subjects	2
4.3.2. EEG Effects of Prolonged Bed Rest	4
4.4. RESULTS	5
4.4.1. Variability of EEG Characteristics Over Time in Control Subjects	5
4.4.2. Variability of EEG Characteristics Over Time in Subjects Undergoing 28 Days of Bed Rest	7
4.5. DISCUSSION: A REASSESSMENT OF THE SKYLAB FINDINGS	9
REFERENCES	12
FIGURES AND TABLES	13

~~PAGE~~ PRECEDING PAGE BLANK NOT FILMED

SECTION 4

SIGNIFICANCE OF EEG CHANGES ASSOCIATED WITH SPACE FLIGHT:

COMPARATIVE STUDIES OF NORMAL INDIVIDUALS AND SUBJECTS

UNDERGOING PROLONGED BED REST

4.1. SUMMARY

In order to provide comparative data for further assessment of the EEG alterations seen during Skylab, two investigations were conducted: (1) the variability of alpha, beta, theta, and delta EEG characteristics was assessed with quantitative computer techniques in a group of six normal individuals over a period of two months, and (2) the EEG effects of a prolonged period of bed rest were evaluated in two subjects.

The results have provided quantitative information which confirms that the inflight EEG changes seen during Skylab were statistically significant, but the absolute values obtained for the various parameters did not exceed the maximal range expected in a normal population. Further, the EEG manifestations of extended bed rest did not appear similar to those of space flight.

4.2. INTRODUCTION

The purpose of this investigation was (1) to define, in precise terms, the variability of alpha, theta, beta, and delta EEG characteristics in a group of normal control individuals, and (2) to determine the effects of a prolonged period of bed rest (28 days) upon selected EEG parameters. The objective of these tasks was to provide quantitative information which would permit a more definitive statement to be made concerning the significance, and possibly eventually the etiology, of certain EEG alterations observed in recordings from Skylab astronauts (see Final Report, Part III, Contract NAS 9-13870).

In routine clinical practice, the alpha rhythm is considered to be quite stable over time in normal subjects. Variations of more than ± 0.5 Hz are unusual. Yet, during Skylab, inflight individual values of more than 1.0 Hz above the preflight mean were observed, appearing in the early inflight period. Other Skylab findings, including inflight increases in amount of beta and delta activity during the awake state, have been shown to be statistically significant. These EEG alterations have been difficult to assess clinically, because the precise range of variability of these parameters in the normal population has not been documented. In the studies described below, six normal subjects were evaluated repeatedly over a period of two months, in order to establish such norms.

Bed rest has long been used as a potential analog of the weightless state and has been used in attempts to study the effects of zero g upon human physiology. Since bed rest is accompanied by changes in the distribution of body fluids (i.e., a loss from the lower extremities) that are somewhat similar to those seen in space flight, but is not accompanied by the vestibular or proprioceptive alterations inherent in the zero-g environment, it has been particularly valuable in attempts to understand the etiology of the medical problems encountered in Skylab. Although EEG has been recorded during several prior bed-rest studies, there has been no evaluation of frequency and amplitude characteristics sufficient to permit a quantitative comparison with the Skylab results. In several studies (Ryback and Lewis, 1971; Ryback et al., 1971a, b), alterations in sleep patterns were observed during prolonged bed rest (primarily, an increase in stages 3 and 4), but measures of EEG characteristics were not reported. EEGs were recorded by Zubek and Wilgosh (1963) in a one-week study of immobilization in ten subjects. (The subjects were allowed to get up briefly at certain specified times.) They reported a decrease in alpha frequency of approximately 0.5 Hz at the end of the test period, compared to the pretest baseline averages, a result opposite to the effect observed during Skylab. Similar findings were reported in a 62-day bed-rest study by Petukhov and Purakhin (1968).

In 1976, NASA conducted a study in which several individuals were confined to bed for a period of 28 days. As a part of this study, EEG was recorded, in order to evaluate sleep characteristics (see Final Report, Part II, Contract NAS 9-13870). This EEG information has been restudied, using quantitative methods, in order to provide additional information pertaining to the Skylab EEG alterations.

A third study, involving EEG recording during parabolic flight and other periods of vestibular stress, was originally a part of this contract. By recording EEG during experimentally induced periods of near weightlessness as well as during periods of altered vestibular function, we had hoped to determine the possible existence of direct vestibular influences upon the electroencephalogram. Unfortunately, the NASA program involving the use of parabolic flight was curtailed in the fall of 1976, and it was not possible to obtain recordings in flight. Contract funds scheduled for this portion of the program were, with the consent of the contract technical monitor, redistributed to permit an expanded analysis of the EEG data obtained during the normative study (see section 4.4.1., below).

4.3. METHODS

4.3.1. EEG Variability in Normal Control Subjects

4.3.1.1. Subjects. Six volunteer subjects were selected to participate in the variability study. No subject with a history of significant medical or psychiatric disorder was accepted, and subjects taking medication or other drugs in dosages sufficient to influence EEG characteristics were excluded.

A summary of the volunteer group is provided below.

<u>Subject</u>	<u>Age</u>	<u>Sex</u>	<u>Medication Use During Study</u>	<u>Dates of Test Protocol</u>
C.H.	48	M	Motrin, 400 mg, q.i.d., 11/5-11/18; occasional Ascriptin	11/1-12/23, 1976
G.K.	27	M	Occasional ASA	11/1-12/23, 1976
E.B.	23	M	Occasional APC, ASA; Lomotil, 1/27-1/29, 2/15	1/10-3/3, 1977
C.S.	24	F	1/2 gr thyroid/day; occasional ASA	11/1-12/23, 1976
J.R.	22	F	Dimacol, 1/9/77; occasional Tylenol, ASA	1/10-3/3, 1977
S.G.	23	F	-	1/11-3/4, 1977

4.3.1.2. EEG Recording. EEGs were recorded under standardized conditions, using conventional techniques and the international system of electrode placement (The ten twenty electrode system, 1958). Analysis was performed on the following electrode derivations: F₁-A₁, F₂-A₂, C₁-A₁, C₂-A₂, O₁-A₁, O₂-A₂, C₁-O₁, and C₂-O₂.

Each EEG recording session lasted approximately 30 min. Environmental stimuli were minimized and standardized across subjects. Each subject was studied at the same time of the day during all examination sessions, to minimize possible circadian variations in EEG characteristics. All signals were recorded on magnetic tape, to permit later off-line analysis of selected epochs from eyes-open and eyes-closed conditions.

The protocol for each monitoring session was as follows:

1. Eyes closed, relaxed (0.5-1 min)
2. Eyes open, relaxed (1-2 min)
3. Eyes open, reading (7-8 min)
4. Eyes open, watching television (10-15 min)
5. Eyes closed, relaxed (1-2 min)

During each of the above conditions, a 30-sec epoch was chosen for computer analysis. For the purposes of this study, only data from the eyes-closed, relaxed conditions was utilized, since they most closely duplicated the presleep Skylab periods for which comparable data is available. Data obtained while reading and watching television may be utilized in future studies of EEG variations associated with specific tasks.

Each subject initially was studied on four consecutive days, to establish the degree of short-term variability. Subsequently, the individual was

evaluated twice weekly, with at least two and no more than three days' interval between tests, over a period of two months. Thus, each person was tested on 18 occasions.

4.3.1.3. Data Analysis. The data was analyzed in essentially the same manner as were the Skylab recordings, as reported in Part III of this Final Report. The general method chosen for quantification of the EEG background activity has been developed in this laboratory over the past ten years (e.g., Carrie, 1969; Carrie and Frost, 1971, 1973; Frost, 1969, 1975; Frost et al., 1973).

The system developed permits simultaneous analysis of eight EEG channels, with each channel being considered in four discrete frequency bands (alpha, beta, theta, and delta). Thus, in terms of digital processing, it is actually a 32-channel acquisition system. The final output of the computational system includes the following parameters:

1. Overall average amplitude value within each of the four frequency ranges
2. The frequency component which has the largest average amplitude in each frequency band, and the actual average amplitude value
3. Average number of waves detected per second in each frequency range
4. The mean, mode, and standard deviation of the wavelength distribution for each frequency band

For a complete description of the analysis scheme, please refer to Final Report, Part III, Contract NAS 9-13870, pages 4 through 6.

4.3.2. EEG Effects of Prolonged Bed Rest

4.3.2.1. Subjects. From the group of six healthy volunteer subjects who participated in the 28-day bed-rest study, two were chosen to take part in the EEG and sleep evaluations:

<u>Subject</u>	<u>Age</u>	<u>Sex</u>	<u>Medication Use During Study</u>	<u>Starting Date</u>
J.H.	26	M	-	June 1976
R.T.	28	M	-	June 1976

4.3.2.2. EEG Recording. EEG, EOG, and EMG recordings were made, using standard techniques and the conventional system of electrode placement. The following derivations were recorded during each session: F₁-C₃, F₂-C₄, C₃-O₁, C₄-O₂, EMG (submental electrode pair), and EOG (electrodes lateral to and above the eye).

Each recording session lasted for eight hours, from approximately 11 p.m. until 7 a.m. Prior to "lights out" each night, the subjects were recorded under standard eyes-open and eyes-closed conditions, to obtain the data for

subsequent quantitative analysis.

All signals were recorded on magnetic tape, to permit later off-line analysis. The signals also were graphically displayed during the eight-hour period on a conventional EEG machine, to permit later analysis of sleep characteristics.

The subjects were studied according to the following schedule: Prior to the start of the bed-rest phase, each subject was monitored during three consecutive nights of sleep, to establish baseline characteristics. During the bed-rest phase, each subject was monitored for 12 nights of the 28-day study. These sessions included the first three nights, the last three nights, and six additional nights, spaced relatively equally throughout the remainder of the bed-rest period (nights 5, 12, 16, 18, 21, and 24). Post-bed rest, each subject was studied during nights one through six.

4.3.2.3. Data Analysis. A computer method identical to that described above for the EEG variability study (Section 4.3.1.3.) was employed to analyze 30-sec waking EEG samples obtained during the presleep portion of each monitoring session.

4.4. RESULTS

4.4.1. Variability of EEG Characteristics Over Time in Control Subjects

4.4.1.1. The Alpha Frequency Range (6.5-13.5 Hz). Preliminary examination of the data revealed that, as expected, the alpha activity predominated in the occipital areas of all subjects (channels C₁-A₁, C₂-A₂, C₁-O₁, and C₂-O₂). Since a central-to-occipital derivation was used during Skylab, the C₁-O₁ and C₂-O₂ channels were selected for detailed consideration.

The results are summarized in Table I, which shows, for each subject, the average (mean), standard deviation (sd), and range (r = highest value minus lowest value) for three EEG parameters (mean frequency, average amplitude, and number of waves/sec), as calculated for the entire test period (i.e., each value listed is the average of all 18 individual test values obtained over the two-month interval). In each case, the individual values were obtained from the initial eyes-closed period of the test sequence. The overall average across subjects is also indicated for each measure.

If the C₁-O₁ (left) channel is considered, the average subject had a mean frequency value of 9.7 Hz (sd ± 0.25), with a maximum range of 0.7 Hz; an average amplitude of 14.9 μ V (sd ± 2.96), with a range of 11.3 μ V; and averaged 8.1 waves/sec over the observation period (sd ± 0.4), with a range of 1.6 waves/sec. On the right side (C₂-O₂), the mean frequency value was 9.8 Hz (sd ± 0.27), with a range of 1.0 Hz; the average amplitude was 15.9 μ V (sd ± 3.13), with a 12.2 μ V range; and the number of waves/sec averaged 8.2 (sd ± 0.46), with a range of 1.5 waves/sec. The two sides thus tended to be quite similar, both with respect to actual values and in terms of variability over time.

A graphic presentation of the variability of these measures over time for the C_1-O_1 EEG channel of each subject is provided by Figs. 1-6. In each figure, the solid line represents the data from which the values of Table I (for the C_1-O_1 channel) were derived, while the dashed line plots the values obtained from the second eyes-closed period of each day. Thus, the extent to which the solid and dashed tracings diverge provides an estimate of the degree of variability to be expected within a time span measured in minutes (typically, 25-30 min). In most cases, the values for the initial and final eyes-closed periods are quite similar for all parameters (e.g., Subject G.K., Fig. 2; Subject E.B., Fig. 3) or show a random relationship over time (e.g., Subject J.R., Fig. 5). In one individual (Subject C.H., Fig. 1), the alpha frequency was consistently lower during the second eyes-closed period, perhaps reflecting a tendency to become drowsy late in the monitoring session.

4.4.1.2. The Beta Frequency Range (13.51-40 Hz). The beta frequency range results for channels C_1-O_1 and C_2-O_2 are summarized in Table II, which is organized in a manner identical to Table I (Section 4.4.1.1.).

The average subject had a mean beta range frequency of 19.7 Hz (sd ± 0.79 Hz) on the left (C_1-O_1) side, with an average maximum range of 3.2 Hz. The corresponding average amplitude was 8.8 μV (sd ± 1.23 μV , range 4.3 μV), and the number of waves/sec was 12.4 (sd ± 1.53), with a range of 5.9 waves/sec. On the right (C_2-O_2) side, the average frequency was 20.1 Hz (sd ± 1.05 Hz), with a range of 3.8 Hz; the average amplitude was 9.6 μV (sd ± 1.60 μV), with a range of 5.8 μV ; and the average number of waves/sec was 13.0 (sd ± 1.94), with a range of 7.2 waves/sec. As in the case of the alpha range, the two sides tended to be almost identical in their beta characteristics.

Figures 7-12 show, graphically, the variability of beta range parameters over the time course of the study for the C_1-O_1 channel for each subject (data for the first [solid line] and last [dashed line] eyes-closed periods of each examination are compared). In general, there was little, if any, consistent difference between the two recording periods over the two-month study, although on a given day a noticeable discrepancy might be seen. In two individuals, however, there was a tendency for the average beta amplitude to be somewhat higher during the final eyes-closed period of each test (Subjects G.K. and S.G.).

4.4.1.3. The Theta Frequency Range (3.5-6.5 Hz). Table III summarizes the theta range results for the C_1-O_1 and C_2-O_2 channels (table format like that of Table I, Section 4.4.1.1.). On the left side (C_1-O_1), the overall average values were as follows: mean frequency, 5.0 Hz (sd ± 0.12), with a range of 0.42 Hz; average amplitude, 8.5 μV (sd ± 1.54 μV), with a range of 5.7 μV ; and number of waves/sec, 2.8 (sd ± 0.28), with a range of 1.1 waves/sec. For the right side (C_2-O_2), the mean frequency was 5.0 Hz (sd ± 0.16 Hz), with a range of 0.6 Hz; the average amplitude was 8.2 μV (sd ± 1.40 μV), with a range of 4.2 μV ; and the number of waves/sec value was 2.8 (sd ± 0.28), with a range of 1.0 waves/sec. The two sides were, again, very similar in all characteristics.

The variability of theta activity over the two-month study period is illustrated in Figs. 13-18 for the C_1-O_1 channel of each subject. (Each graph compares the daily results for the initial eyes-closed period [solid

line] and the final eyes-closed period [dashed line].) While the two daily periods were, in general, quite similar or varied randomly, two subjects (C.H. and S.G.) tended to have fewer theta frequency waves (decreased number of waves/sec) during the second eyes-closed period (Figs.13 and 18).

4.4.1.4. The Delta Frequency Range (0.5-3.5 Hz). The delta frequency range results are summarized in Table IV for C₁-O₁ and C₂-O₂ derivations (table format like that of Table I, Section 4.4.1.1.). For the C₁-O₁ (left) channel, the overall average values were: mean frequency, 2.2 Hz (sd ± 0.18 Hz), with a range of 0.6 Hz; average amplitude, 8.0 μ V (sd ± 1.31 μ V), with a range of 5.2 μ V; and the average number of waves/sec was 1.5 (sd ± 0.17), with a range of 0.7 waves/sec. On the right side (C₂-O₂), the mean frequency averaged 2.2 Hz (sd ± 0.14 Hz), with a range of 0.5 Hz; the average amplitude was 7.7 μ V (sd ± 1.01 μ V), with a range of 3.8 μ V; and the average number of waves/sec was 1.7 (sd ± 0.13), with a range of 0.5 waves/sec. Again, the two sides tended to be very similar in terms of their EEG characteristics.

Figures 19-24 illustrate the degree of variability over the study period for the C₁-O₁ channel of each subject for both the initial eyes-closed (solid lines) and final eyes-closed (dashed lines) recording conditions. As with the other frequency ranges, there was, typically, no consistent difference between the two recording periods, although apparently random variation was often present.

4.4.2. Variability of EEG Characteristics Over Time in Subjects Undergoing 28 Days of Bed Rest

Samples for detailed analysis were obtained during the presleep period of each monitoring session, while the subject was fully awake but in the eyes-closed state. In order to facilitate comparisons with the normative study and with the Skylab results, analysis was restricted to a single channel (C₁-O₁). A Mann-Whitney U test was utilized in order to assess the significance of the apparent changes in the various parameters during the test and post-test conditions for individual subjects, compared to the baseline period. A probability value of $p \approx 0.05$ was considered to be statistically significant.

Tables V-VIII show the average values, standard deviations, and ranges of the three major EEG parameters for each of the test conditions (i.e., prestudy, or baseline; bed-rest phase; and the poststudy, or recovery, period). The individual values from which these averages were determined are plotted over the time course of the bed-rest study for each subject and for the four EEG frequency ranges in Figs. 25-32. (In each of these figures, the mean value for each parameter in the pretest period is projected across the test period as a dashed line.)

4.4.2.1. Alpha Frequency Range (Table V)

4.4.2.1.1. Subject J.H. (Fig. 25). The mean frequency showed more fluctuation during the bed-rest phase than during the prestudy session, with a suggestion of two periods of elevation: one early (days 1 and 2) and one relatively late (days 16-24). The bed-rest average value of 10.0 Hz was not, however, significantly different from the prestudy value of 9.7 Hz. The frequency tended to increase in the latter portion of the poststudy phase

(days +4 to +6), and the average of 10.1 Hz was significantly elevated, compared to the prestudy mean ($p < 0.05$).

A greater range of amplitude values was also observed during bed rest, but there were no significant changes in the mean values, either during bed rest or in the poststudy period.

The number of waves/sec measure averaged 8.5 in the prestudy phase and was significantly elevated in both the bed-rest period (9.5, $p < 0.02$) and the post-test phase (9.6, $p < 0.05$).

4.4.2.1.2. Subject R.T. (Fig. 26). There were no significant alterations or obvious trends in the mean frequency or number of waves/sec measures. The average amplitude values were likewise not significantly altered; however, there was a transient elevation near the end of the bed-rest period (days 26-28), which persisted into the poststudy phase (days +1 and +2).

4.4.2.2. Beta Frequency Range (Table VI)

4.4.2.2.1. Subject J.H. (Fig. 27). There were no significant alterations detected during the bed-rest or poststudy periods, and no trends were evident in the plots of the individual values.

4.4.2.2.2. Subject R.T. (Fig. 28). The mean frequency and number of waves/sec parameters were not significantly altered over the course of the study. The average amplitude tended to decrease slightly during bed rest (not significant) and was significantly ($p < 0.02$) depressed in the poststudy period (9.3 μV prestudy, 7.7 μV poststudy).

4.4.2.3. Theta Frequency Range (Table VII)

4.4.2.3.1. Subject J.H. (Fig. 29). While there were no statistically significant changes in any of the measured variables, there was a tendency for the number of waves/sec values to be slightly decreased during the bed-rest period, with a recovery in the poststudy phase.

4.4.2.3.2. Subject R.T. (Fig. 30). There were no significant alterations seen over the course of the study, and no obvious trends.

4.4.2.4. Delta Frequency Range (Table VIII)

4.4.2.4.1. Subject J.H. (Fig. 31). No significant changes in the delta frequency range parameters were seen during or following the bed-rest study.

4.4.2.4.2. Subject R.T. (Fig. 32). The mean frequency measure tended to decline slightly during the bed-rest period (prestudy 2.2 Hz, bed rest 2.0 Hz), reaching a minimum value on day 12. This finding was, however, not statistically significant. The average amplitude rose from 6.3 μV in the prestudy period to 8.3 μV during bed rest ($p < 0.05$), then declined to a baseline level in the poststudy period.

No significant change in the number of waves/sec measure was observed.

4.5. DISCUSSION: A REASSESSMENT OF THE SKYLAB FINDINGS

As outlined in a previous report (Part III, Final Report, Contract NAS 9-13870), several waking EEG alterations were found in Skylab crew members. The most consistent findings were an inflight increase in the amounts of beta and theta frequency activity and an elevation of the average alpha frequency. The current results, obtained from individuals under controlled 1-g conditions, may be utilized as a reference data set against which the Skylab values may be compared.

4.5.1. The Alpha Frequency Range

Two of the Skylab astronauts (O.G. and E.G.) had significant ($p < 0.05$) increases in the average alpha frequency parameter, inflight. The third (J.K.) had a similar but nonsignificant trend. Subject E.G. (84-day flight) showed the most clear-cut alterations: The preflight average frequency was 9.2 Hz, with a range of 0.8 Hz (8.9 to 9.7 Hz). Inflight, the average value rose to 9.8 Hz, with a range of 1.0 Hz (10.3 Hz to 9.3 Hz). The highest inflight value, 10.3 Hz, was seen on the first inflight recording day (day 3) and represented a 1.2 Hz change from the last-obtained preflight value (9.1 Hz). The overall range, preflight, inflight, and postflight, was 1.4 Hz (8.9 Hz to 10.3 Hz).

Examination of Table I shows that one of the six individuals of the normative study (S.G.) had an alpha frequency range as great as that found in Skylab astronaut E.G., and another (Subject E.B.) showed a range only slightly lower (1.3 Hz, C₂-O₂ channel). Thus, considering only total range of the alpha frequency measure, it must be concluded that the Skylab results are within the range expected in a normal population.

Although these results indicate that the Skylab frequency range itself is apparently not atypical, the pattern with which the individual values occurred over time was shown to be statistically significant by application of a nonparametric statistical evaluation (Mann-Whitney U test). Thus, the cluster of inflight values was more consistently elevated above the preflight grouping than would be expected by random selection within the established total range ($p < 0.05$, in the case of E.G. and O.G.).

This latter aspect may be compared with the results of the bed-rest study (Table V). Neither subject of this study had a total range of alpha frequency values as great as that of Skylab Subject E.G. (J.H. = 1.2 Hz, R.T. = 0.7 Hz). In addition, in neither case was the bed-rest period marked by a significant elevation of the alpha frequency, compared to the prestudy portion, although Subject J.H. had transient elevations near the beginning and end of the study.

Based upon these comparisons, it may be concluded that, with respect to the alpha frequency measure: (1) the Skylab findings are within the overall range of variation to be expected in a normal, earth-based population, but (2) within this normal range, the Skylab inflight values tend to be clustered near the upper portion of the normal range in a nonrandom distribution, and further (3) such clustering was not associated with periods of prolonged bed rest in a 1-g environment.

4.5.2. The Beta Frequency Range

Only one statistically significant EEG alteration was common to all three Skylab astronauts: An inflight increase in the average number of beta frequency waves detected per unit of time. As with the alpha changes, this finding was most pronounced in the case of Subject E.G. (84-day flight), where the average inflight increase was 186%. Individual Skylab values for the number of waves/sec measure were as follows:

<u>Subject</u>	<u>Number of Waves/Sec - Beta Range</u>				
	<u>Preflight</u>	<u>Inflight</u>	<u>Increase</u>	<u>p</u>	<u>Total Range</u>
J.K. (28 day)	5.7	7.3	28%	<0.10	3.0
O.G. (59 day)	5.6	7.2	28%	<0.05	4.4
E.G. (84 day)	2.8	8.0	186%	<0.01	9.2

Comparison of these values with the corresponding results of the normative study (Table II) indicates that, as with the alpha, the Skylab results are not atypical with respect to the overall variability, or range, of the number of waves/sec parameter. With respect to Skylab Subject E.G., the preflight value of 2.8 is somewhat below the normative range, while the inflight average of 8.0 is actually more typical. The major inflight alteration thus again appears to be (as in the case of the alpha frequency) an inflight redistribution or clustering of values toward the upper portion of an individual's own overall range of variability for this EEG characteristic. This clustering represents a significant nonrandom deviation from the expected distribution, based upon the preflight results.

The bed-rest study results (Table VI), on the other hand, while showing a similar overall variability, indicate no tendency for the values to be elevated, or grouped in the upper range, during the period of bed rest.

With respect to the beta frequency range, it may then be concluded that (1) the Skylab findings, viewed individually, are within the total range of variation to be expected in a normal population; (2) the inflight measures of average number of beta waves/sec, while consistently within the normal range, tend to be nonrandomly clustered in the upper portion of the individual's total range; and (3) such nonrandom clustering, which results in an elevation of the average inflight values, was not seen in either of the subjects of the bed-rest study.

4.5.3. The Delta Frequency Range

Two of the Skylab subjects showed small, but statistically significant, inflight increases in the number of delta waves/unit of time measure, while the third showed a similar but nonsignificant tendency. The individual average values for the number of waves/sec measure were as follows:

<u>Subject</u>	<u>Number of Waves/Sec - Delta Range</u>				
	<u>Preflight</u>	<u>Inflight</u>	<u>Increase</u>	<u>p</u>	<u>Total Range</u>
J.K. (28 day)	0.7	1.0	43%	<0.10	0.6
O.G. (59 day)	1.3	1.5	15%	n.s.	0.8
E.G. (84 day)	0.9	1.3	44%	<0.10	1.0

When these results are compared to Table IV, which indicates the findings of the normative study with respect to the delta characteristics, it is again obvious that the Skylab values are not unique with respect to their variability. The significant finding is, again, a nonrandom clustering of values in the upper portion of the individual ranges during the inflight period, thus resulting in increased values for the inflight averages. Inspection of Table VIII also indicates that this tendency for a relative inflight increase in number of waves/sec did not occur during a period of prolonged bed rest.

The conclusions are thus similar to those indicated above for the alpha and beta ranges: (1) the variability of the delta range measure during Skylab did not exceed the maximal range seen in a normal population, but (2) the individual inflight number of waves/sec values tended to be more concentrated in the upper portion of the normal range than would be expected by random variation, and (3) this behavior did not occur during bed rest.

4.5.4. Conclusion

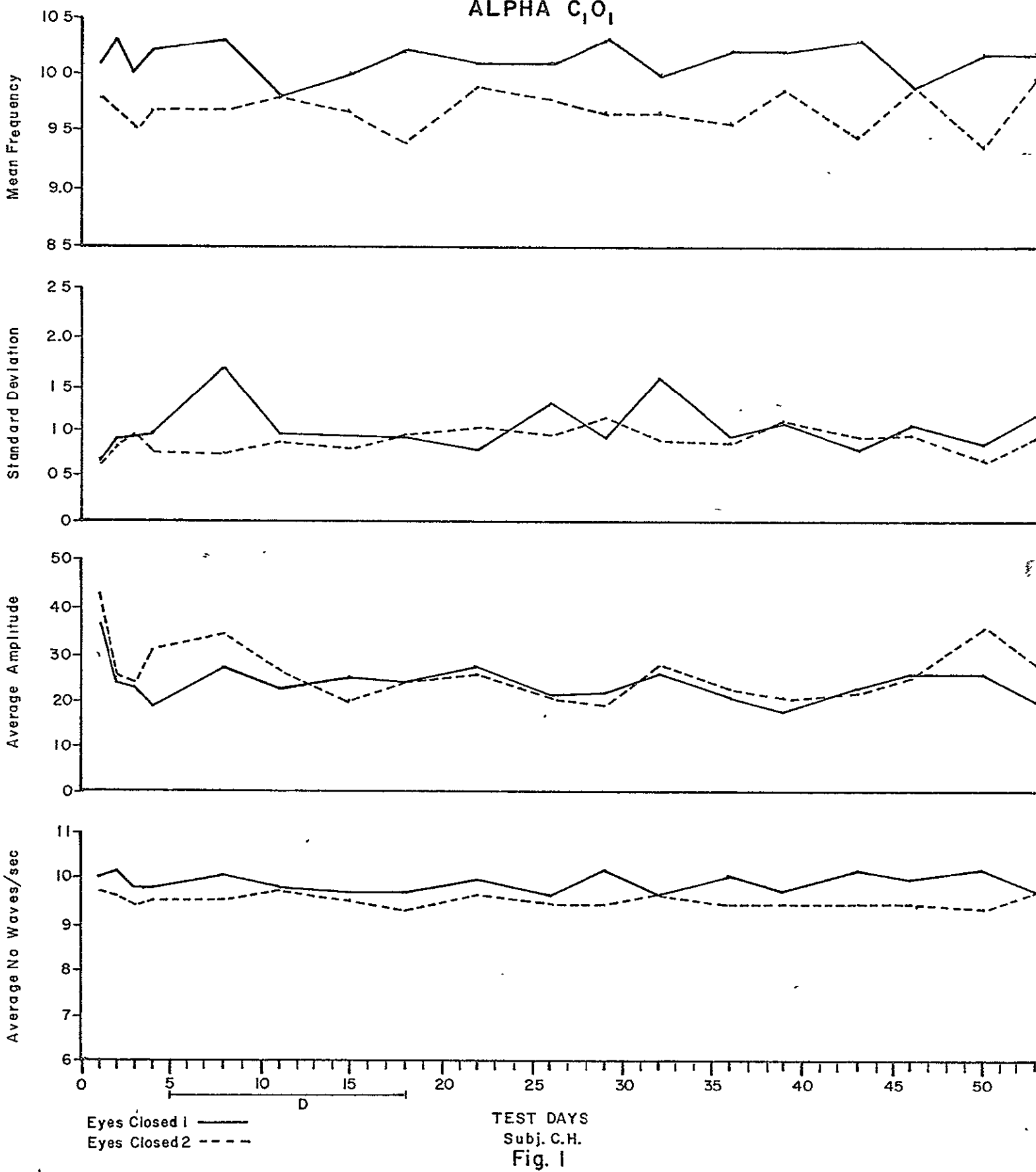
The results of these studies have provided quantitative confirmation of the tentative conclusion made in the original report of the Skylab EEG characteristics (Final Report, Part III, Contract NAS 9-13870): While the apparent inflight EEG alterations were statistically significant, the absolute values attained were never outside the range of normal variation. In addition, it is clear that while some relatively minor EEG changes were seen during a period of prolonged bed rest, in no instance were the alterations like those associated with space flight.

REFERENCES

- Carrie, J. R. G. The modal alpha wavelength. Electroencephalogr. Clin. Neurophysiol., 1969, 27: 703.
- Carrie, J. R. G. and Frost, J. D., Jr. A small computer system for EEG wavelength-amplitude profile analysis. Int. J. Biomed. Comput., 1971, 2: 251-263.
- Carrie, J. R. G. and Frost, J. D., Jr. Wavelength-amplitude profile analysis in clinical EEG. In P. Kellaway and I. Petersen (Eds.), Automation of Clinical Electroencephalography. Raven Press, New York, 1973, pp. 65-74.
- Frost, J. D., Jr. Wavelength analysis of the EEG — the alpha profile. Electroencephalogr. Clin. Neurophysiol., 1969, 27: 702-703.
- Frost, J. D., Jr. Final Report, Contract NAS 9-12974, Skylab Sleep Monitoring Experiment, Appendix, 1975.
- Frost, J. D., Jr., Carrie, J. R. G., Borda, R. P. and Kellaway, P. The effects of Dalmane (flurazepam hydrochloride) on human EEG characteristics. Electroencephalogr. Clin. Neurophysiol., 1973, 34: 171-175.
- Petukhov, B. N. and Purakhin, Y. N. Effect of prolonged bed rest on cerebral biopotentials of healthy subjects. Space Biol. Med. (Moscow), 1968, 2: 56-61.
- Ryback, R. S. and Lewis, O. F. Effects of prolonged bed rest on sleep patterns in young, healthy volunteers. Electroencephalogr. Clin. Neurophysiol., 1971, 31: 395-399.
- Ryback, R. S., Lewis, O. F. and Lessard, C. S. Psychobiologic effects of prolonged bed rest (weightlessness) in young, healthy volunteers (study II). Aerospace Med., 1971a, 42: 529-535.
- Ryback, R. S., Trimble, R. W., Lewis, O. F. and Jennings, C. C. Psychobiologic effects of prolonged weightlessness (bed rest) in young, healthy volunteers (study I). Aerospace Med., 1971b, 42: 408-415.
- The ten twenty electrode system of the International Federation. Electroencephalogr. Clin. Neurophysiol., 1958, 10: 371-375.
- Zubek, J. P. and Wilgosh, L. Prolonged immobilization of the body: Changes in performance and in the electroencephalogram. Science, 1963, 140: 306-308.

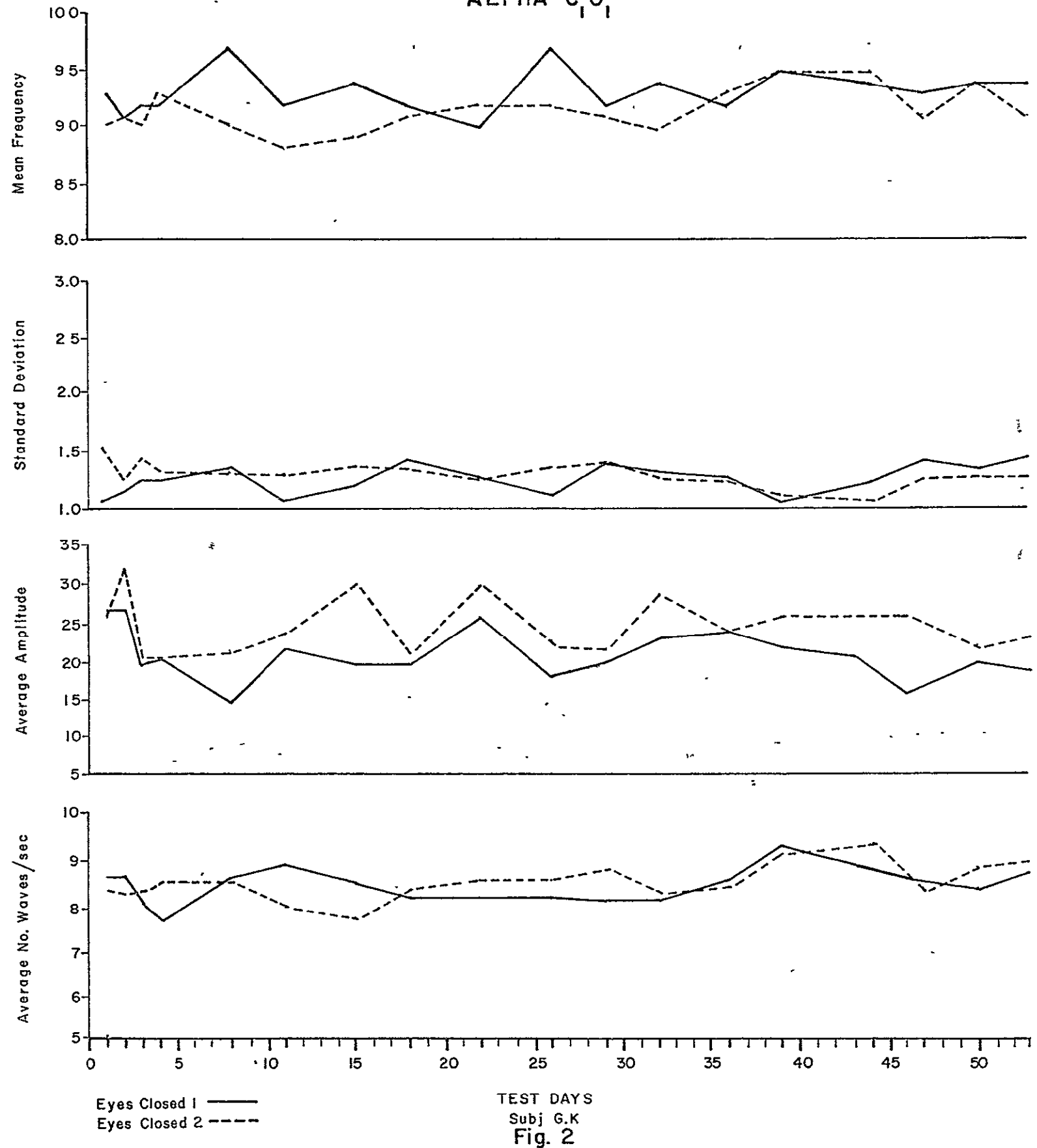
FIGURES AND TABLES

ALPHA C₁O₁



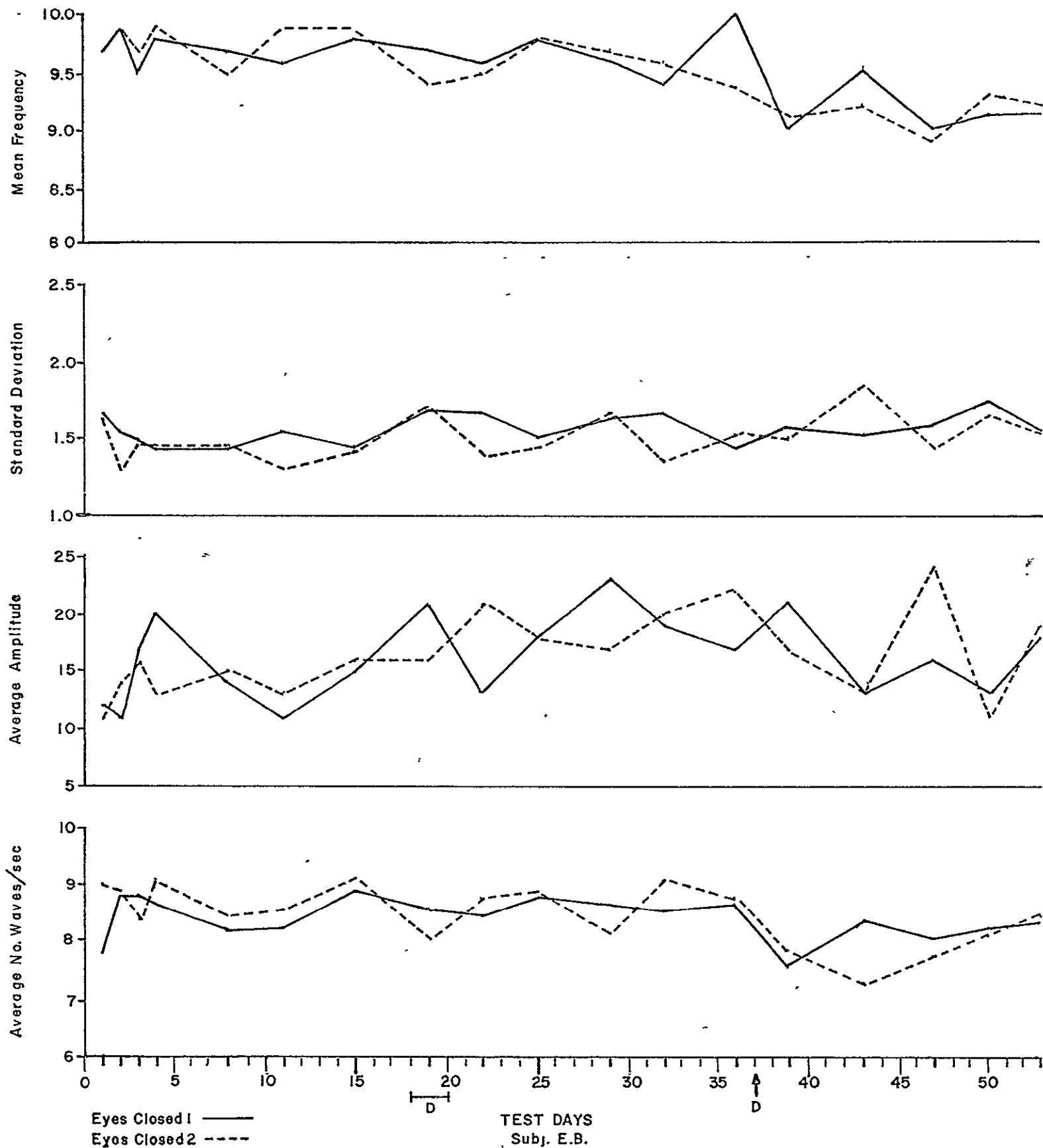
Subj. C.H.
Fig. 1

ALPHA C₁O₁

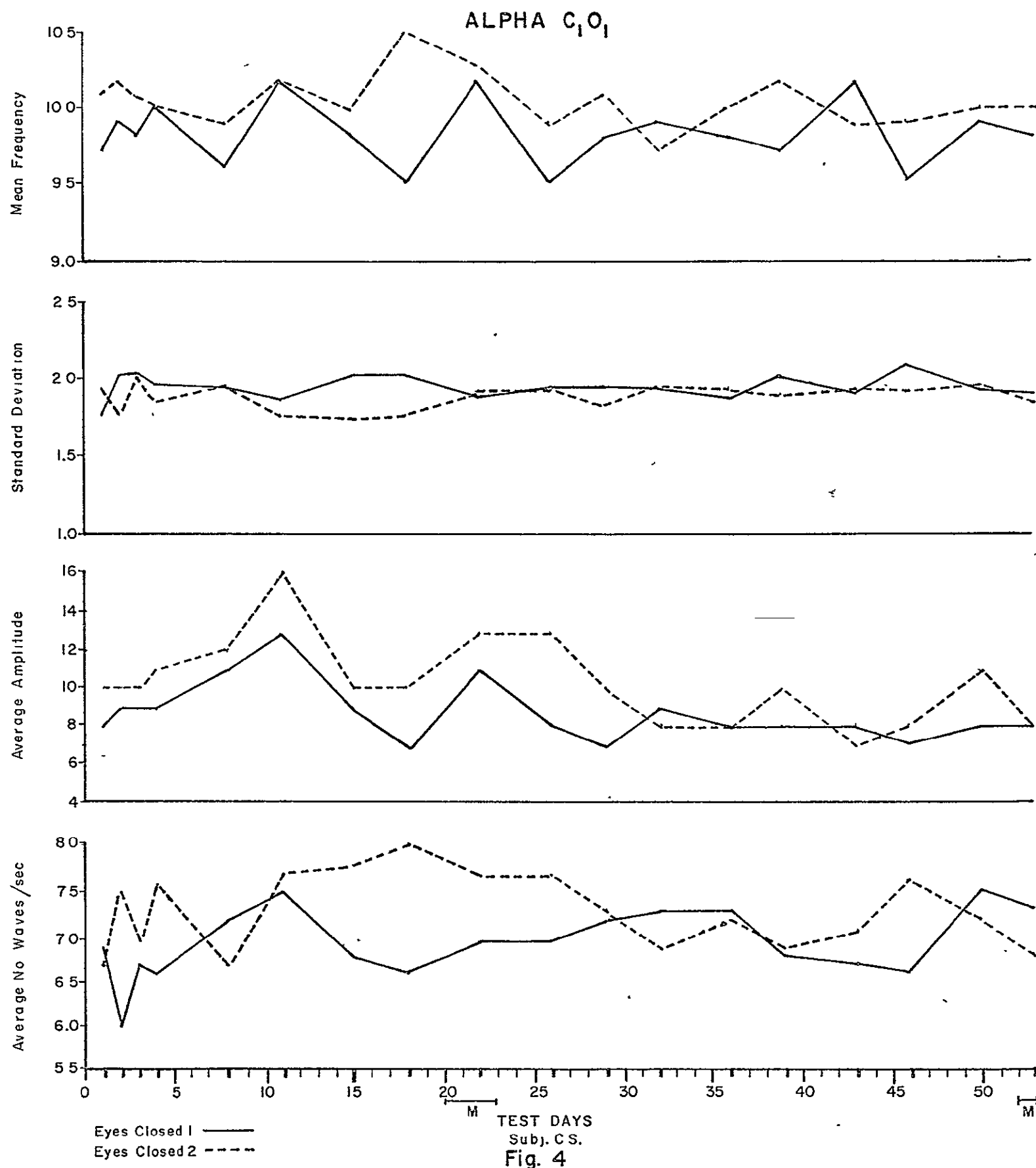


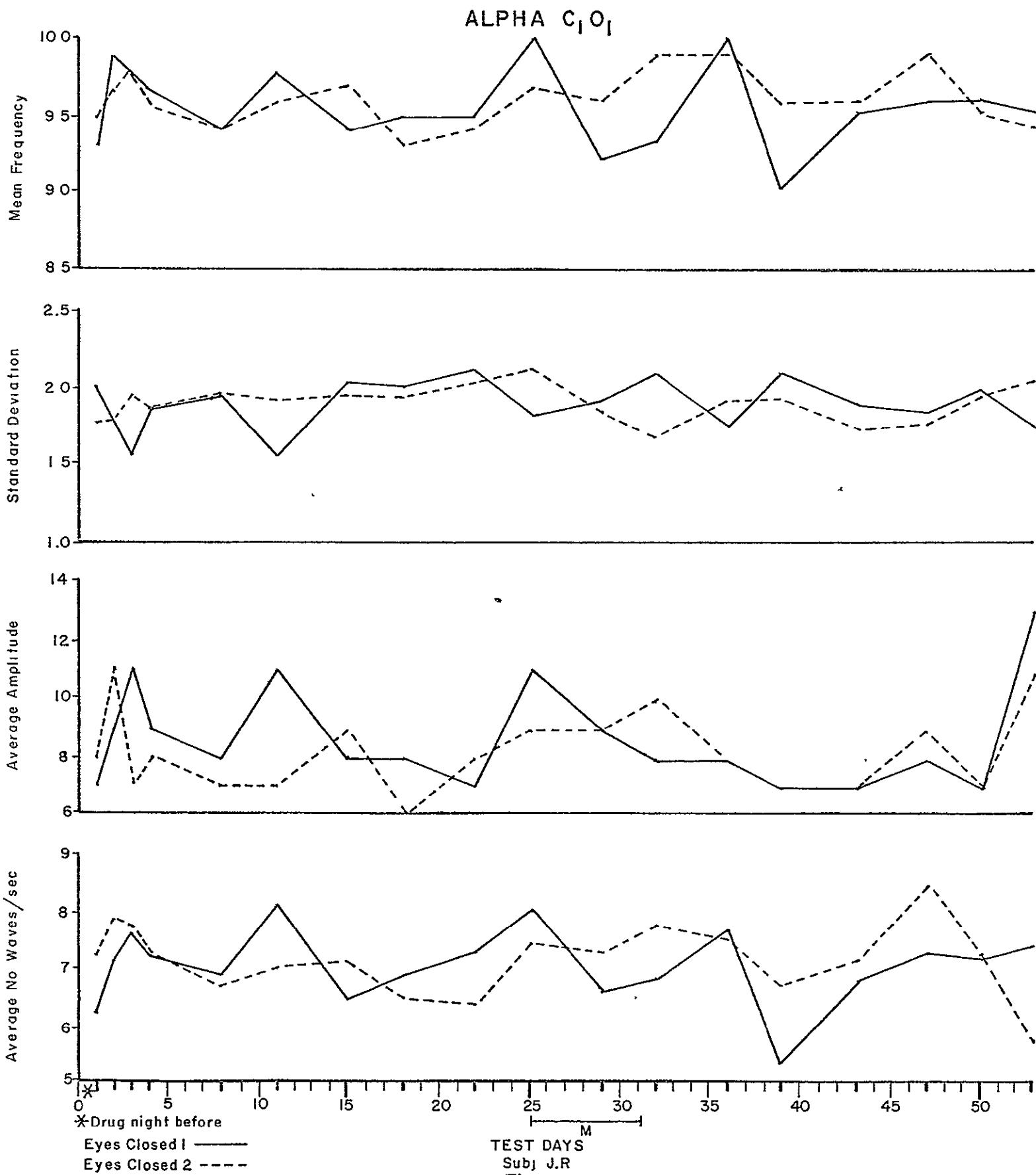
TEST DAYS
Subj G.K
Fig. 2

ALPHA C₁O₁

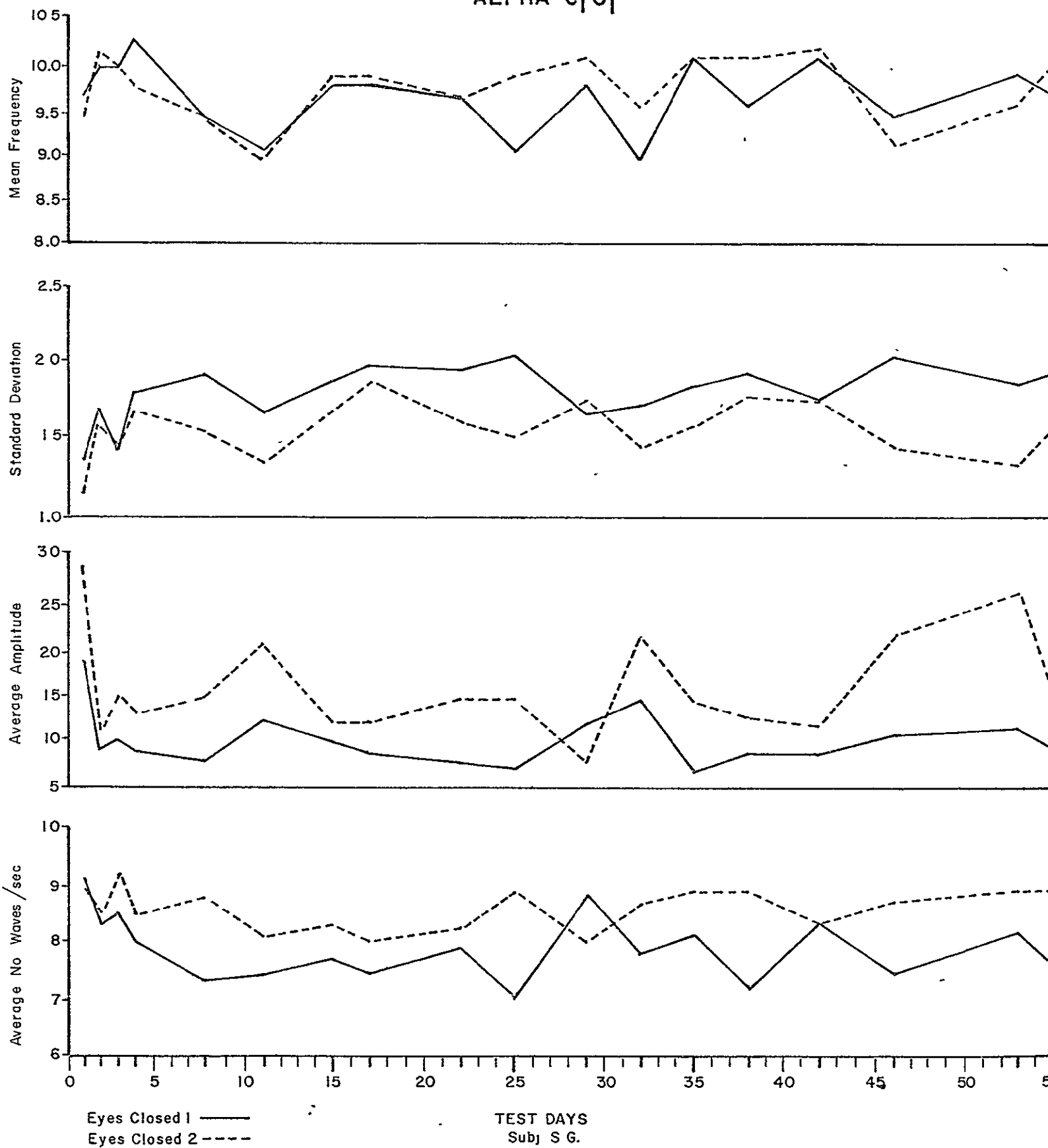


TEST DAYS
Subj. E.B.
Fig. 3



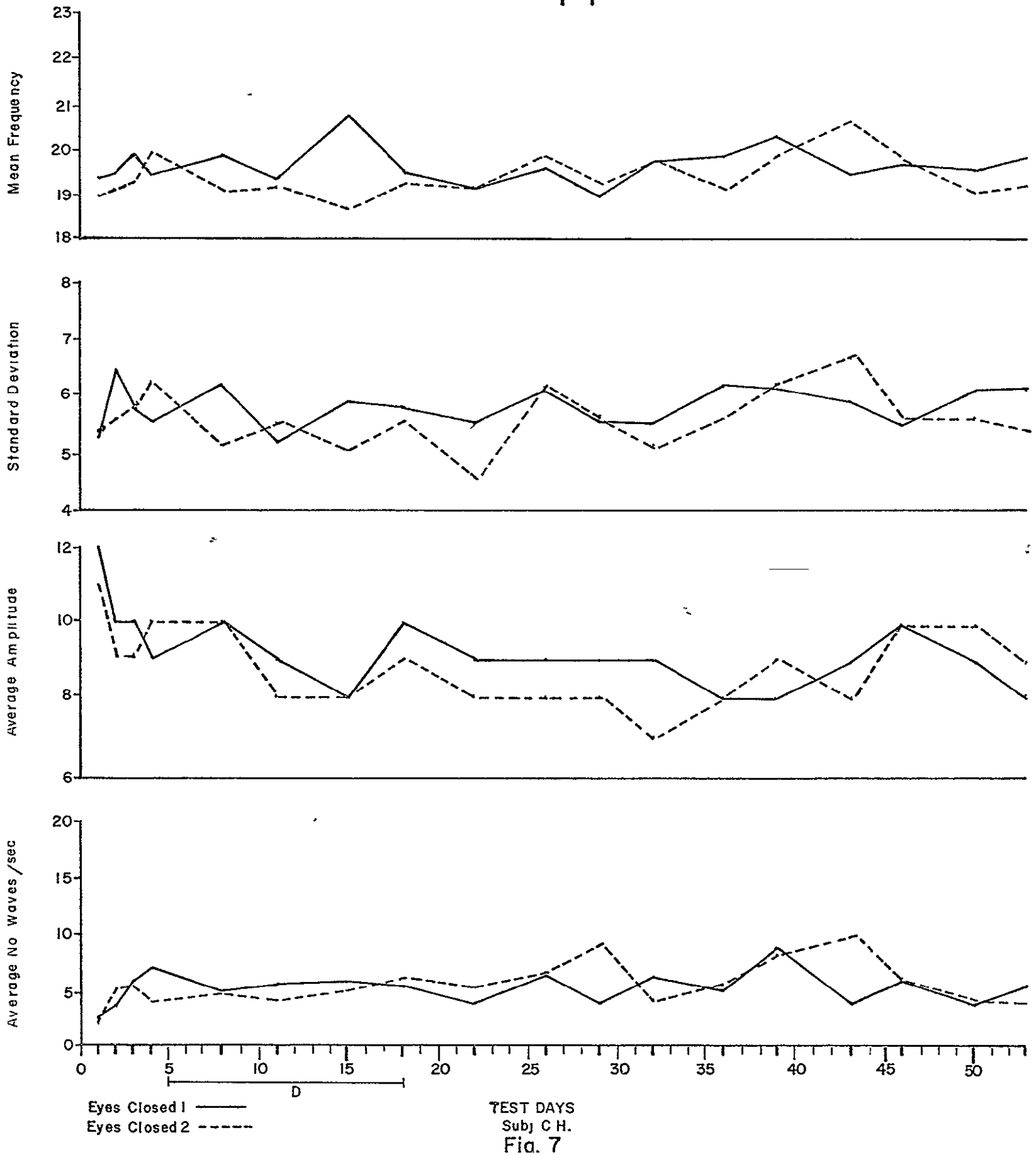


ALPHA C₁O₁

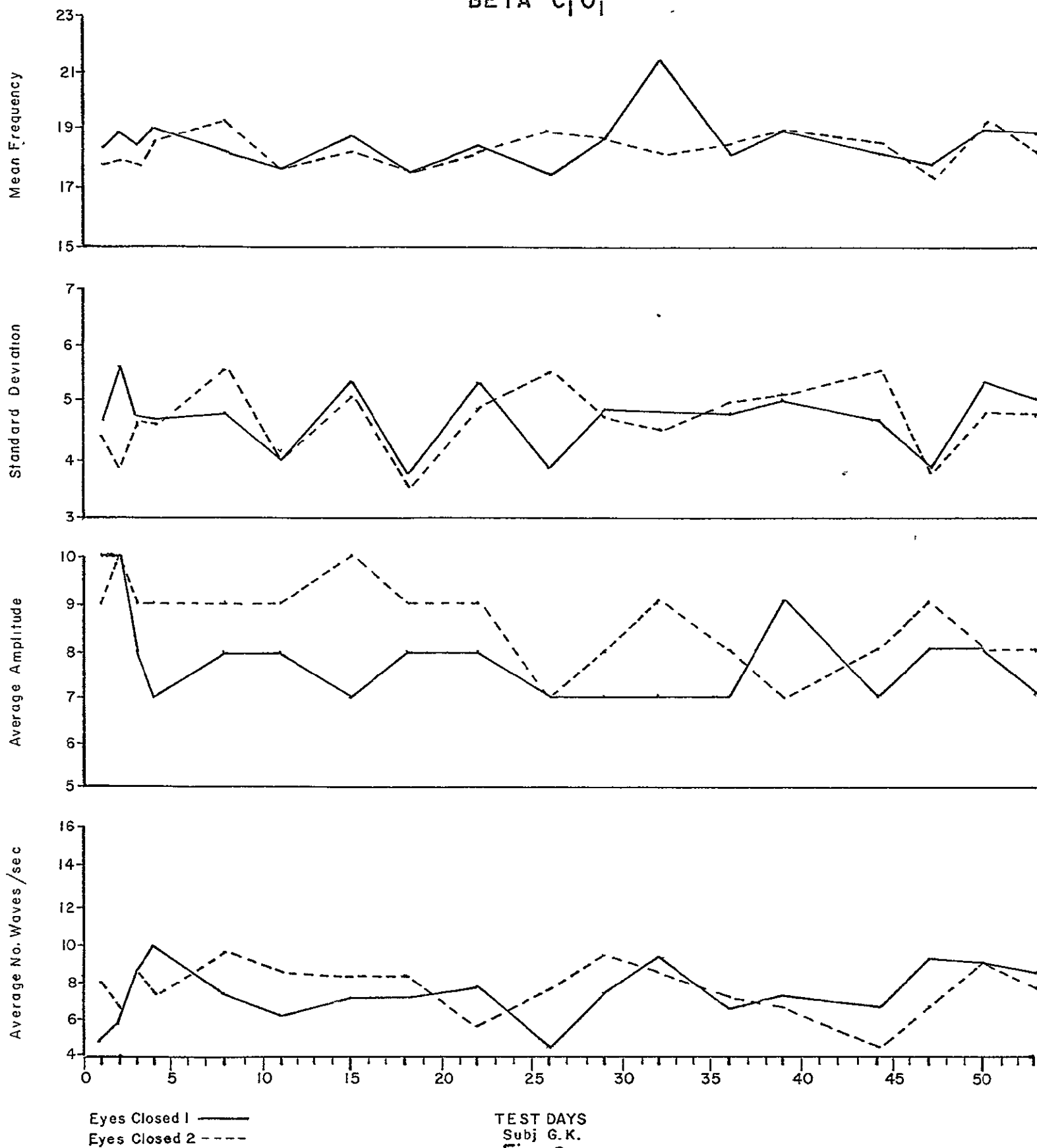


TEST DAYS
Subj S.G.
Fig. 6

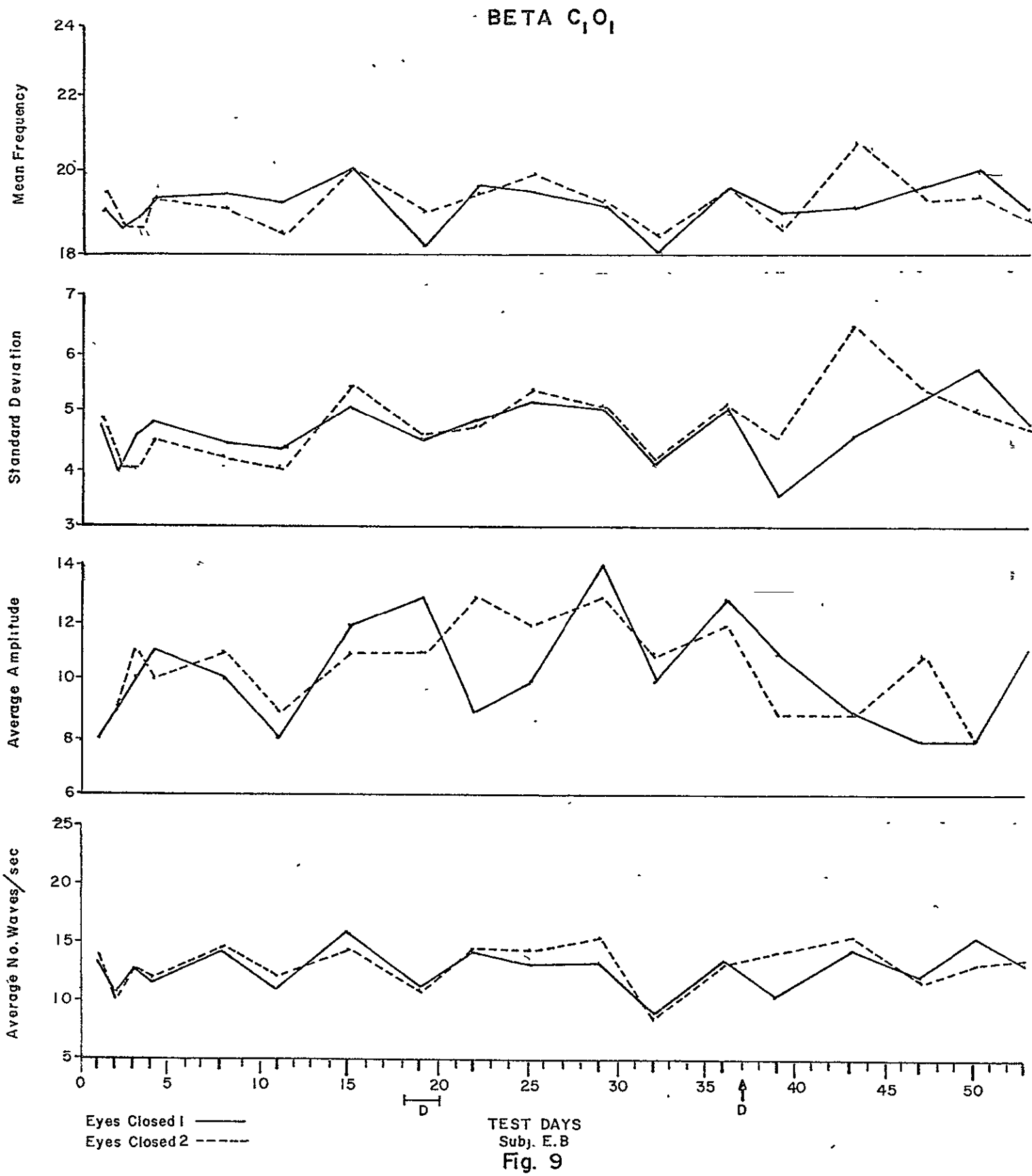
BETA C₁O₁



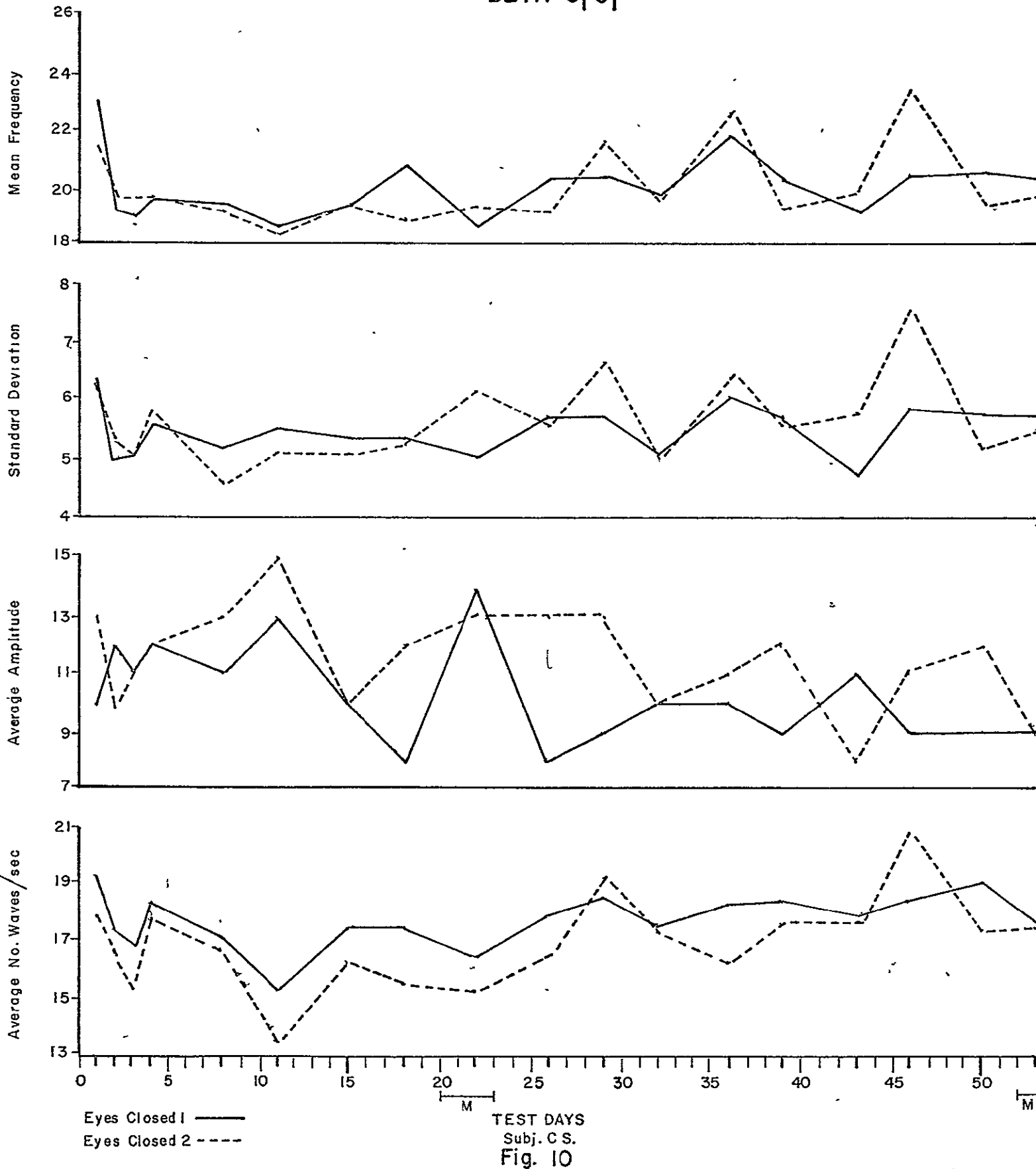
BETA C₁O₁



TEST DAYS
Subj G.K.
Fig. 8

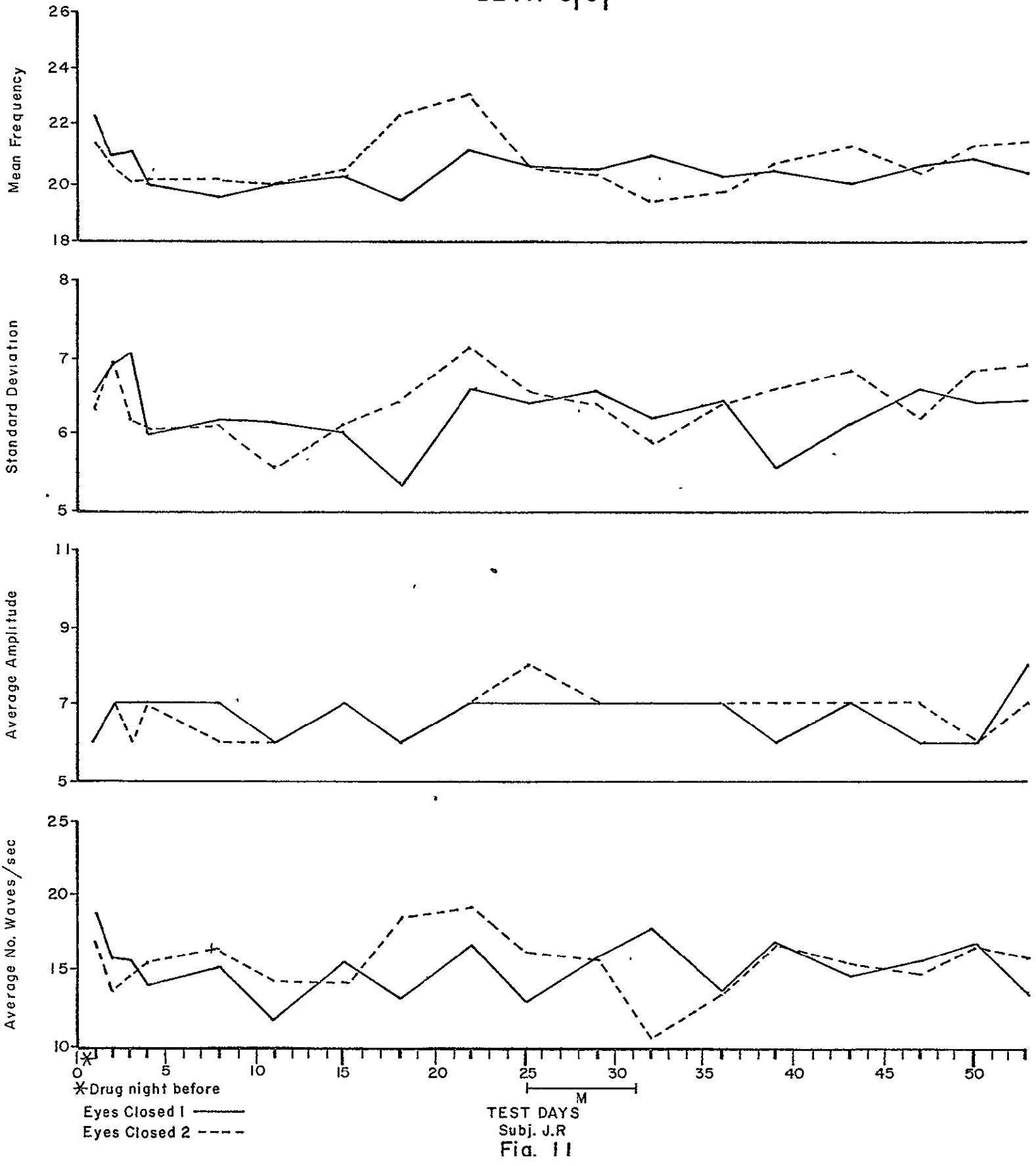


BETA C₁O₁

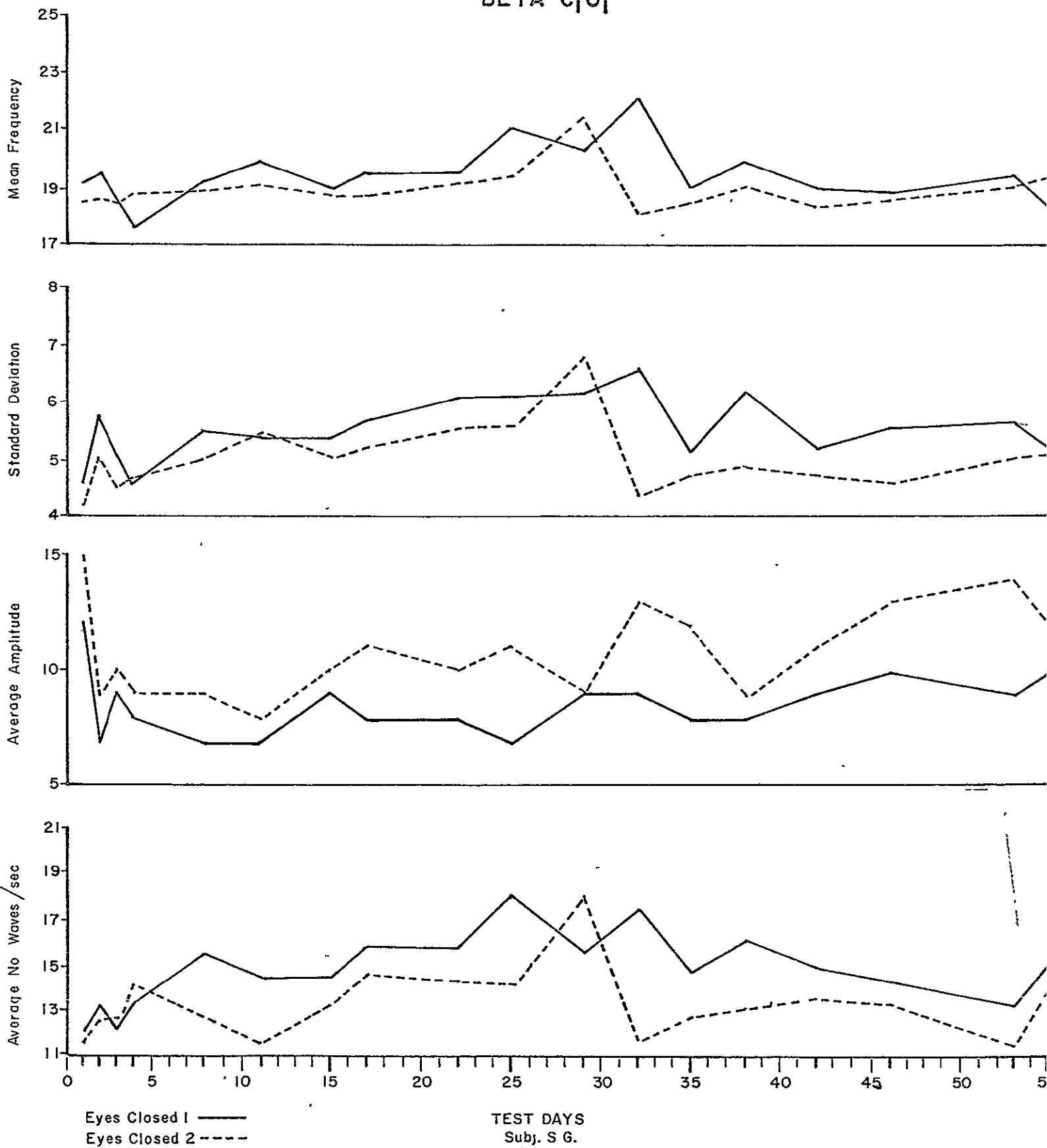


TEST DAYS
Subj. C.S.
Fig. 10

BETA C₁O₁

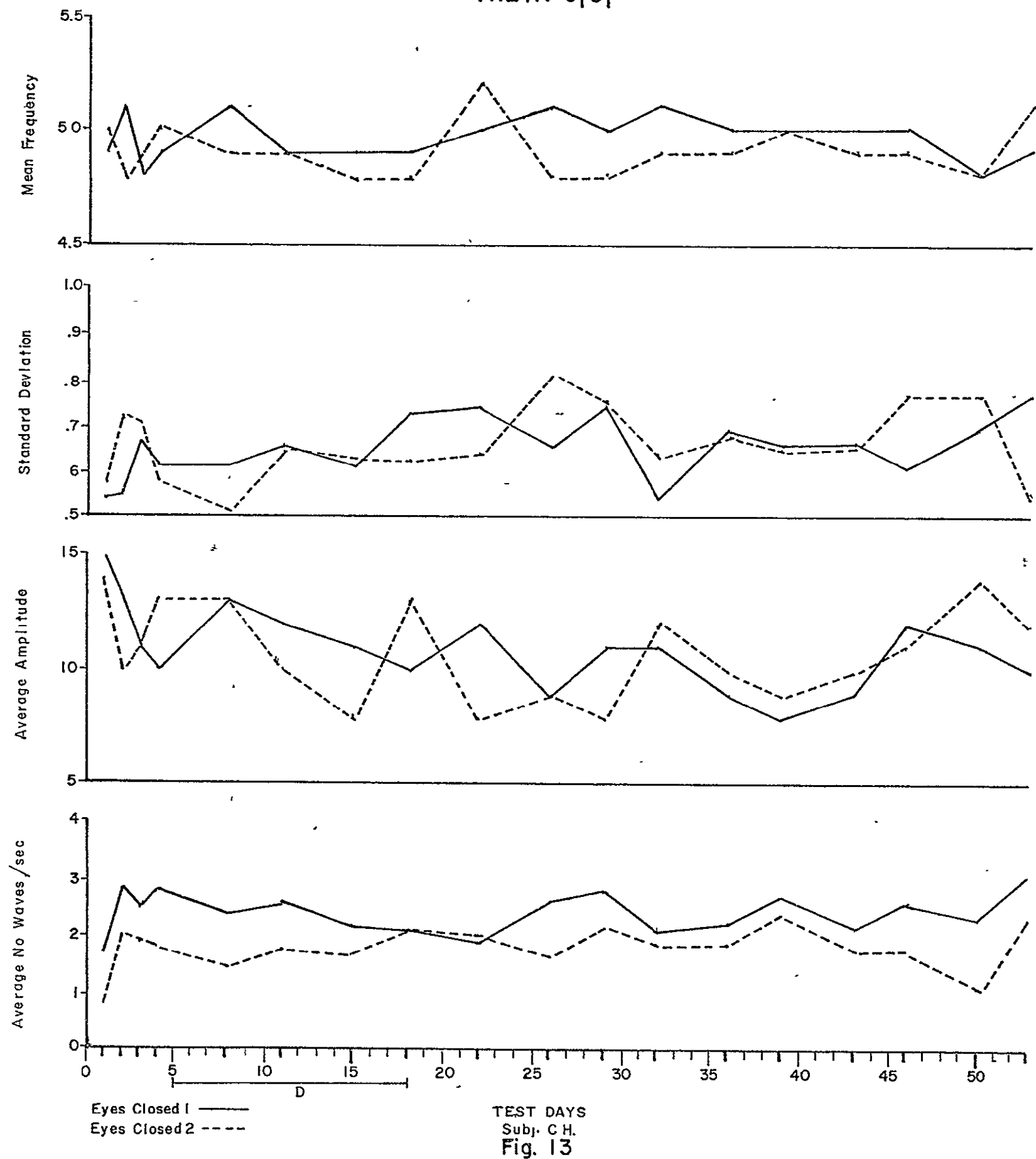


BETA C₁O₁

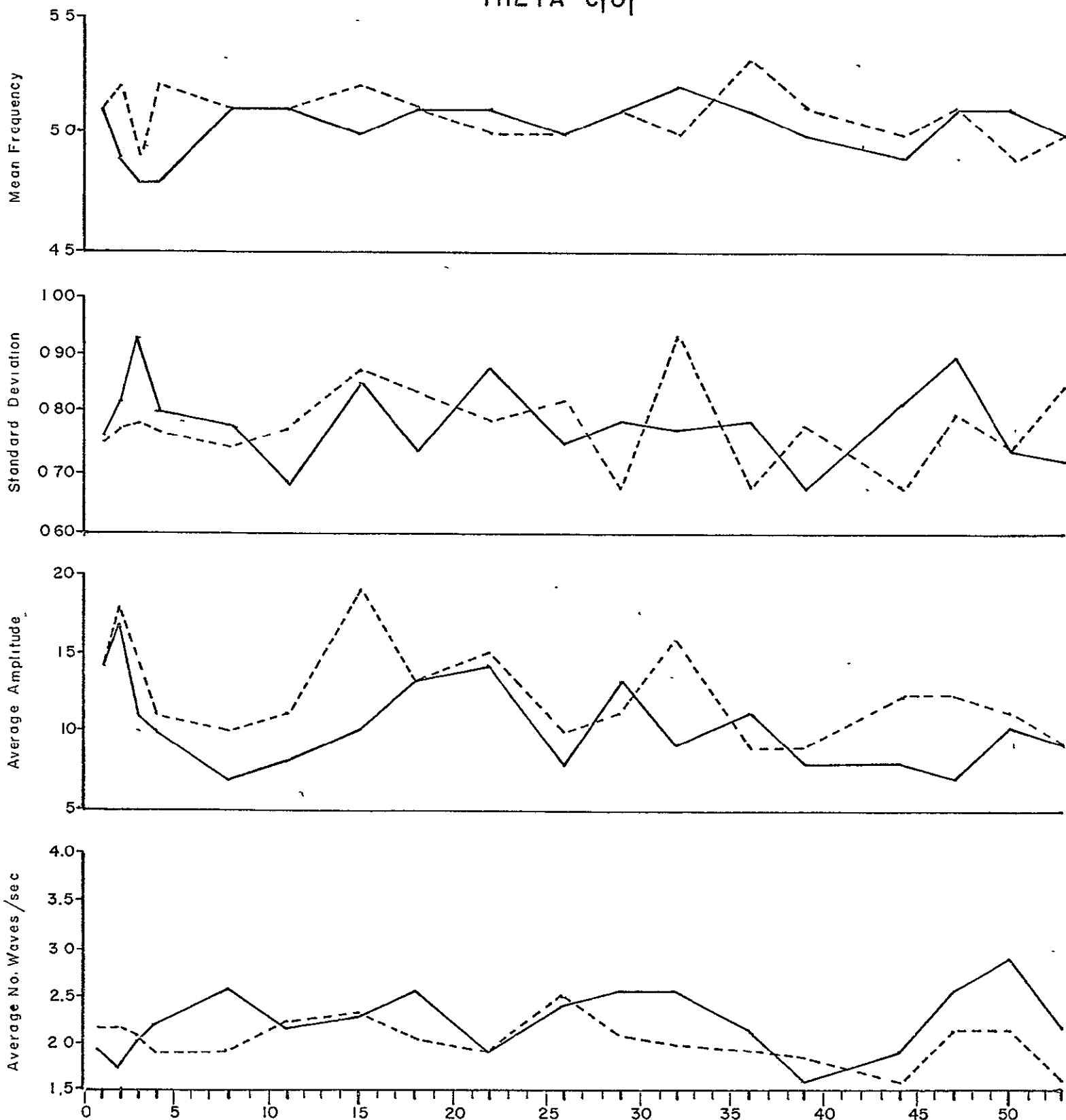


TEST DAYS
Subj. S G.
Fig. 12

THETA C₁O₁

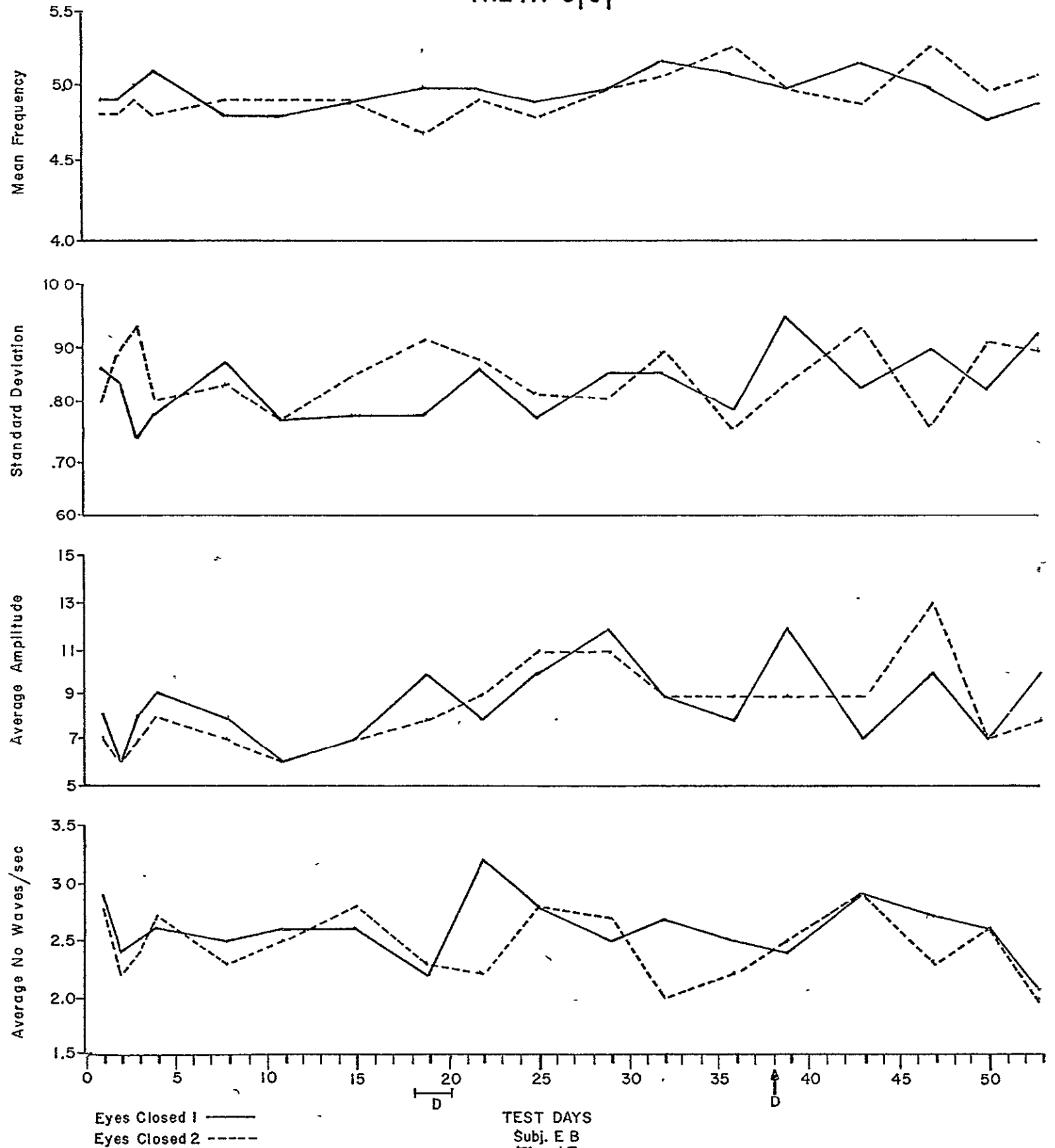


THETA C₁O₁



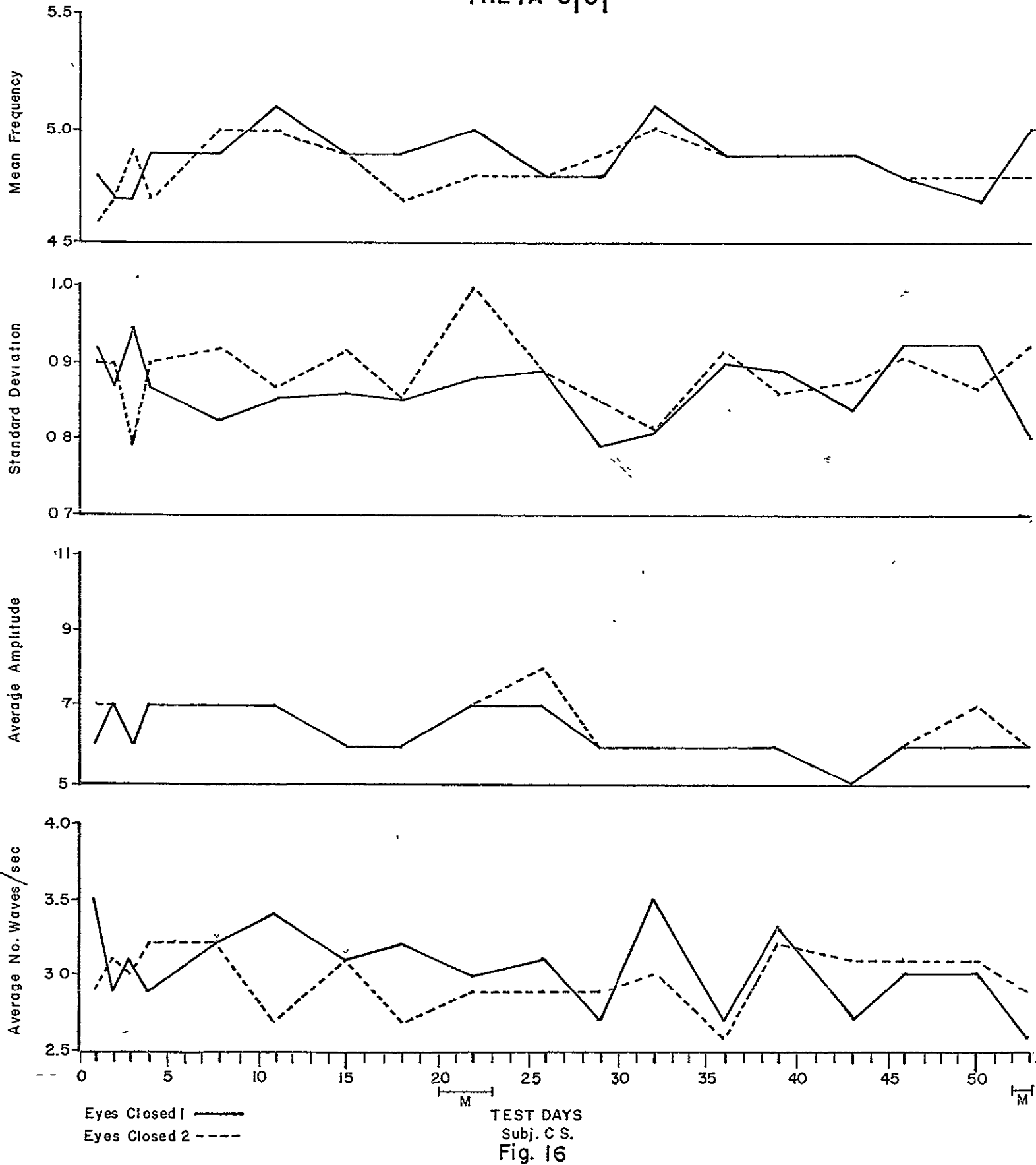
TEST DAYS
Subj. G.K.
Fig. 14

THETA C₁O₁

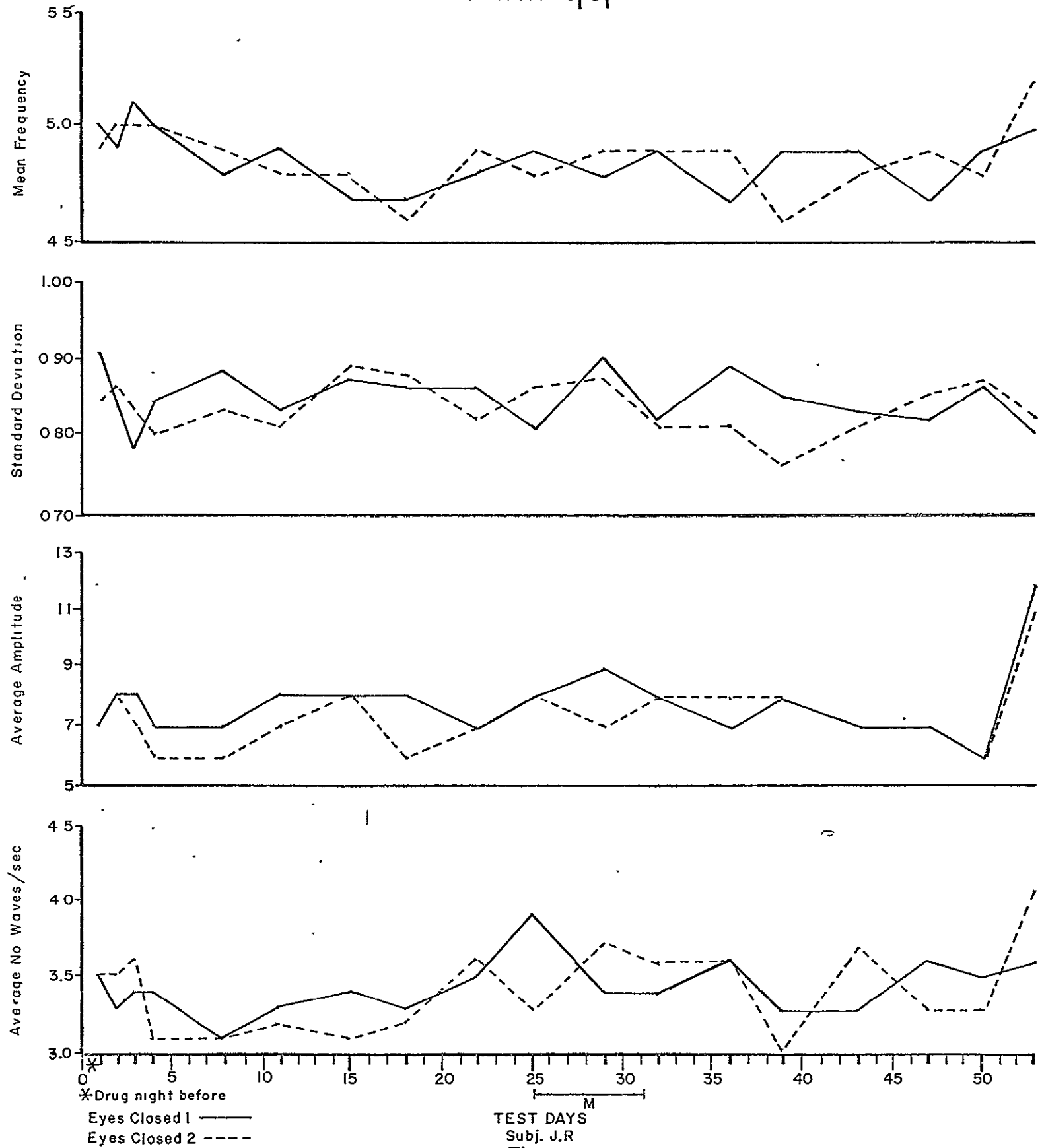


TEST DAYS
Subj. E B
Fig. 15

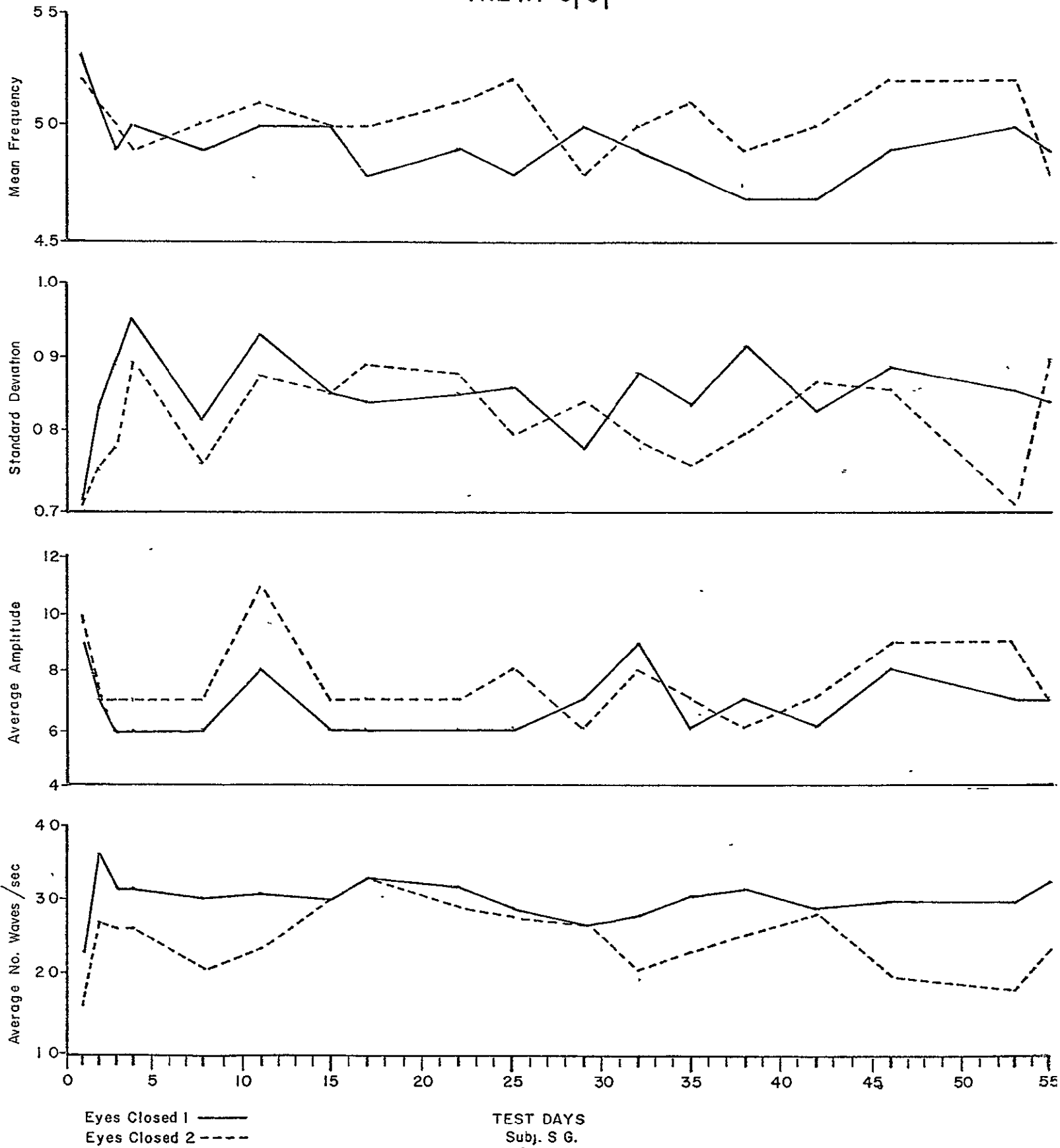
THETA C₁O₁



THETA C₁O₁

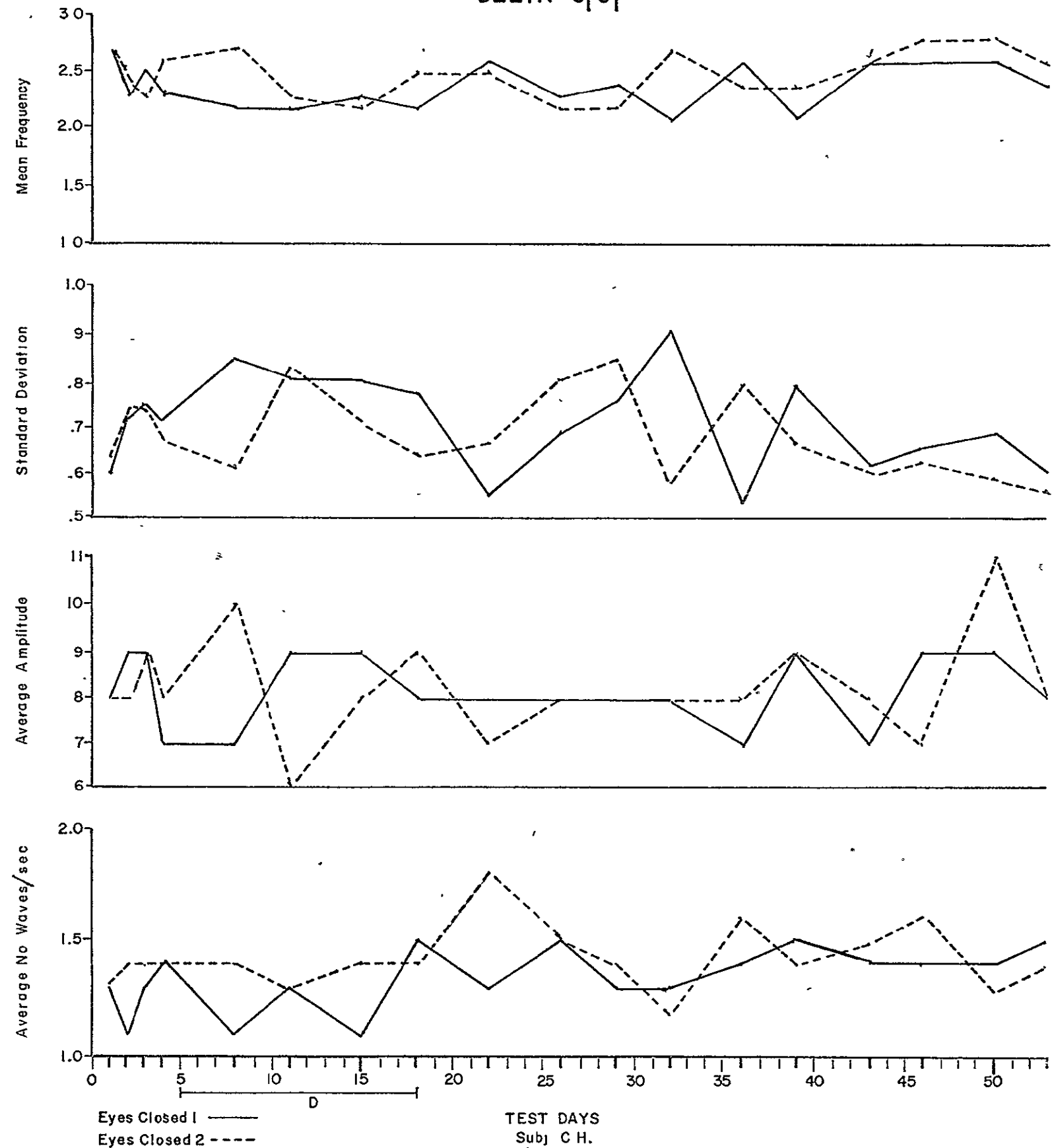


THETA C₁O₁



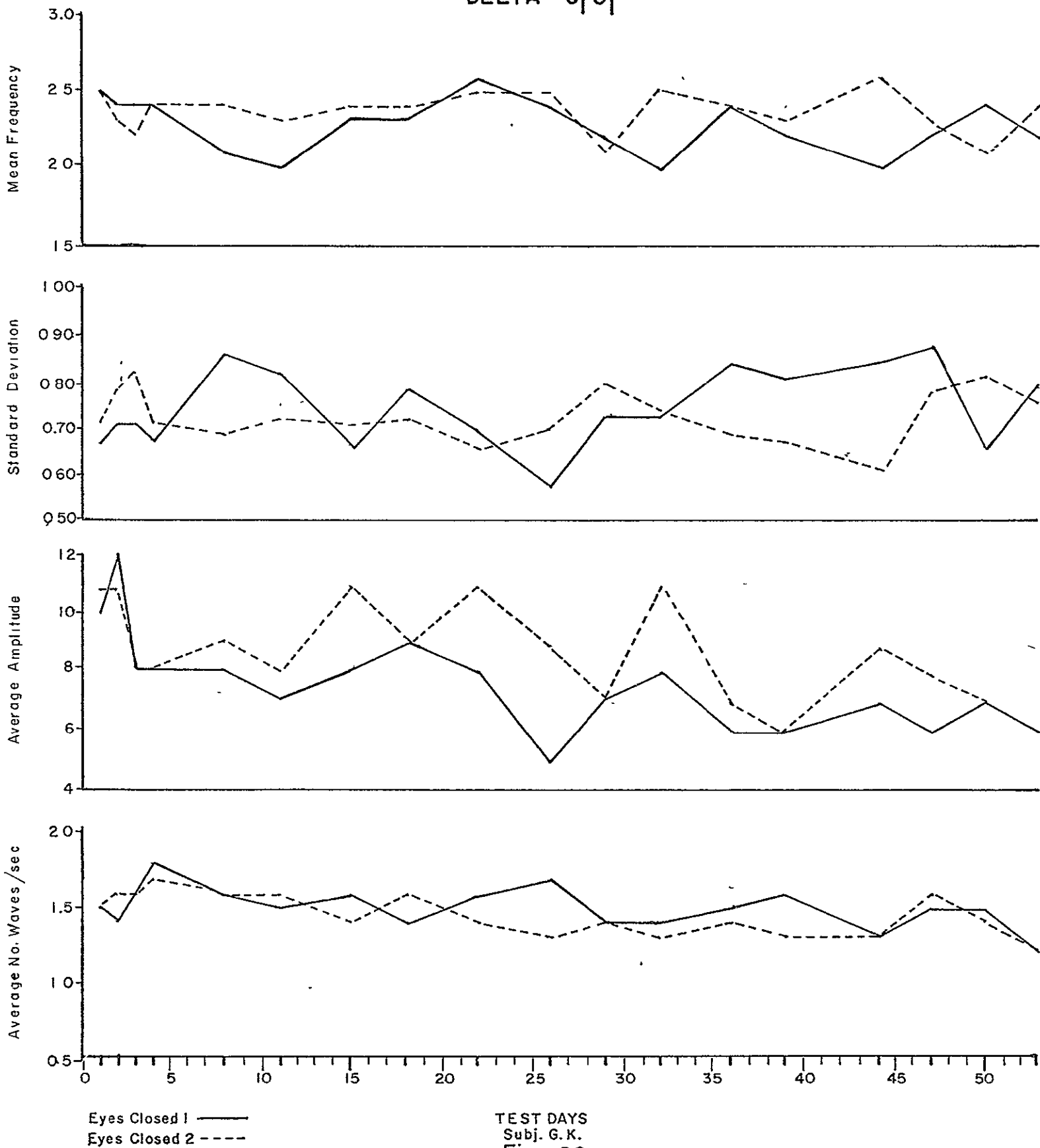
TEST DAYS
Subj. S G.
Fig. 18

DELTA C₁O₁



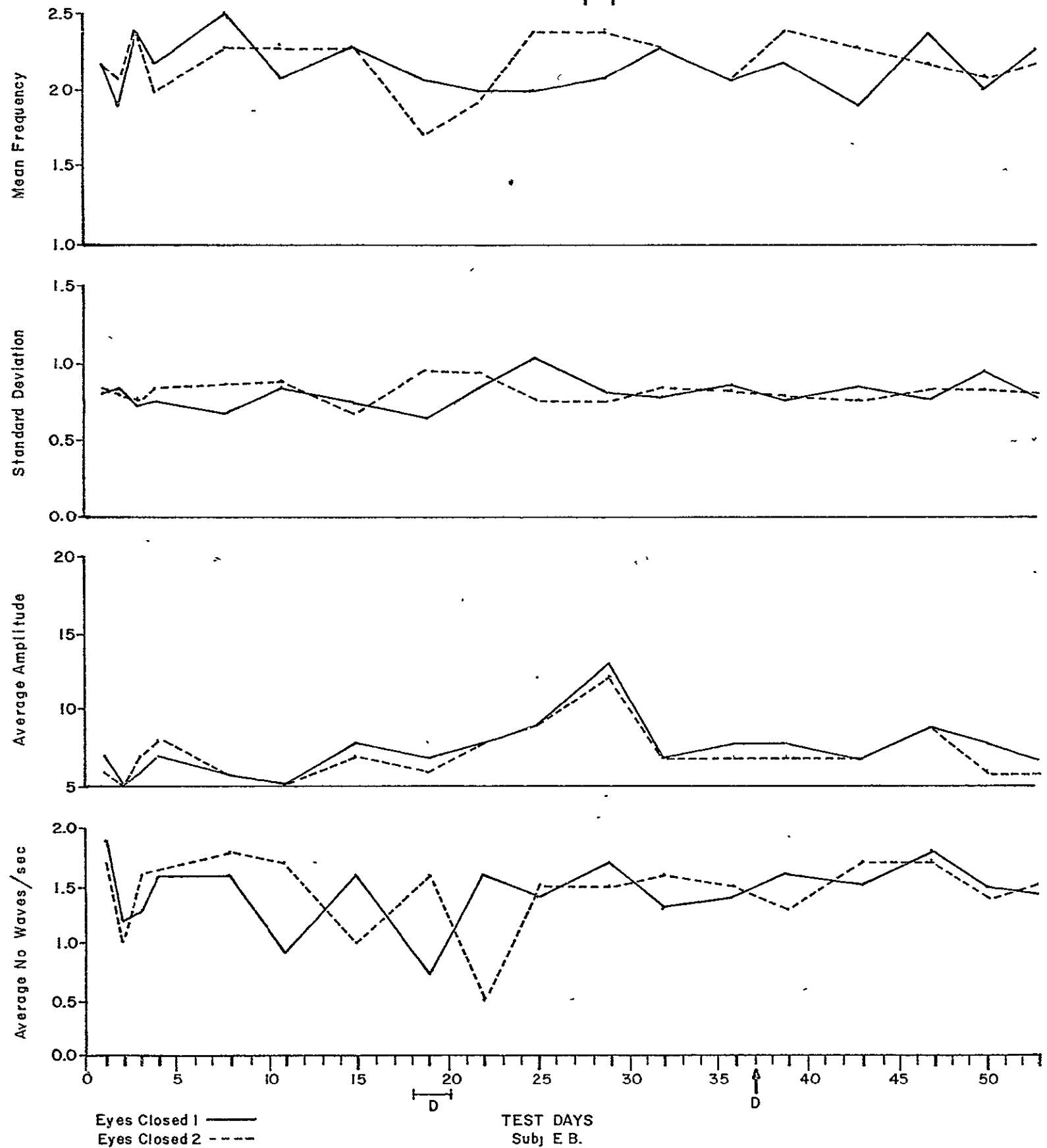
TEST DAYS
 Subj C H.
 Fig. 19

DELTA C₁O₁



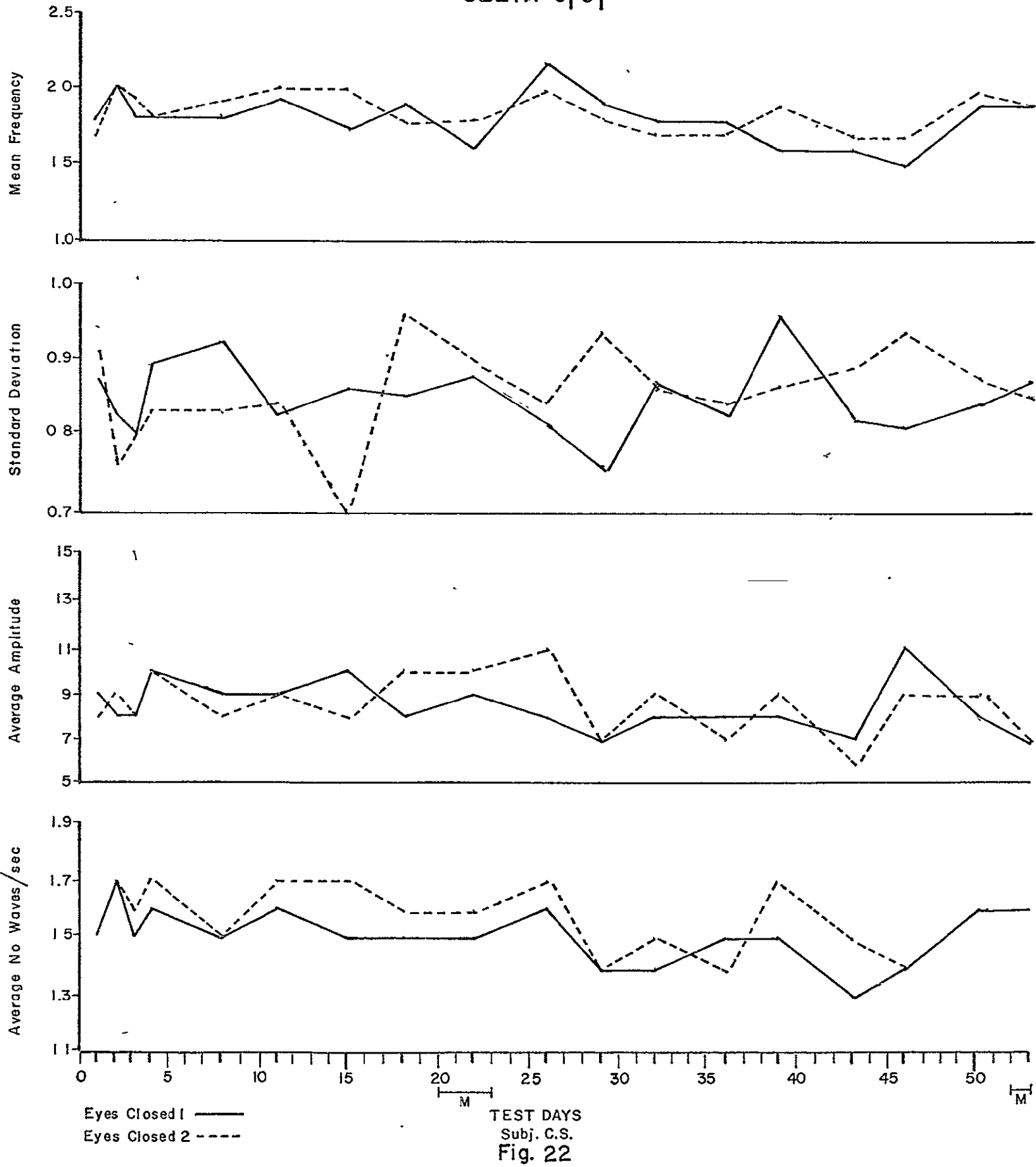
TEST DAYS
Subj. G.K.
Fig. 20

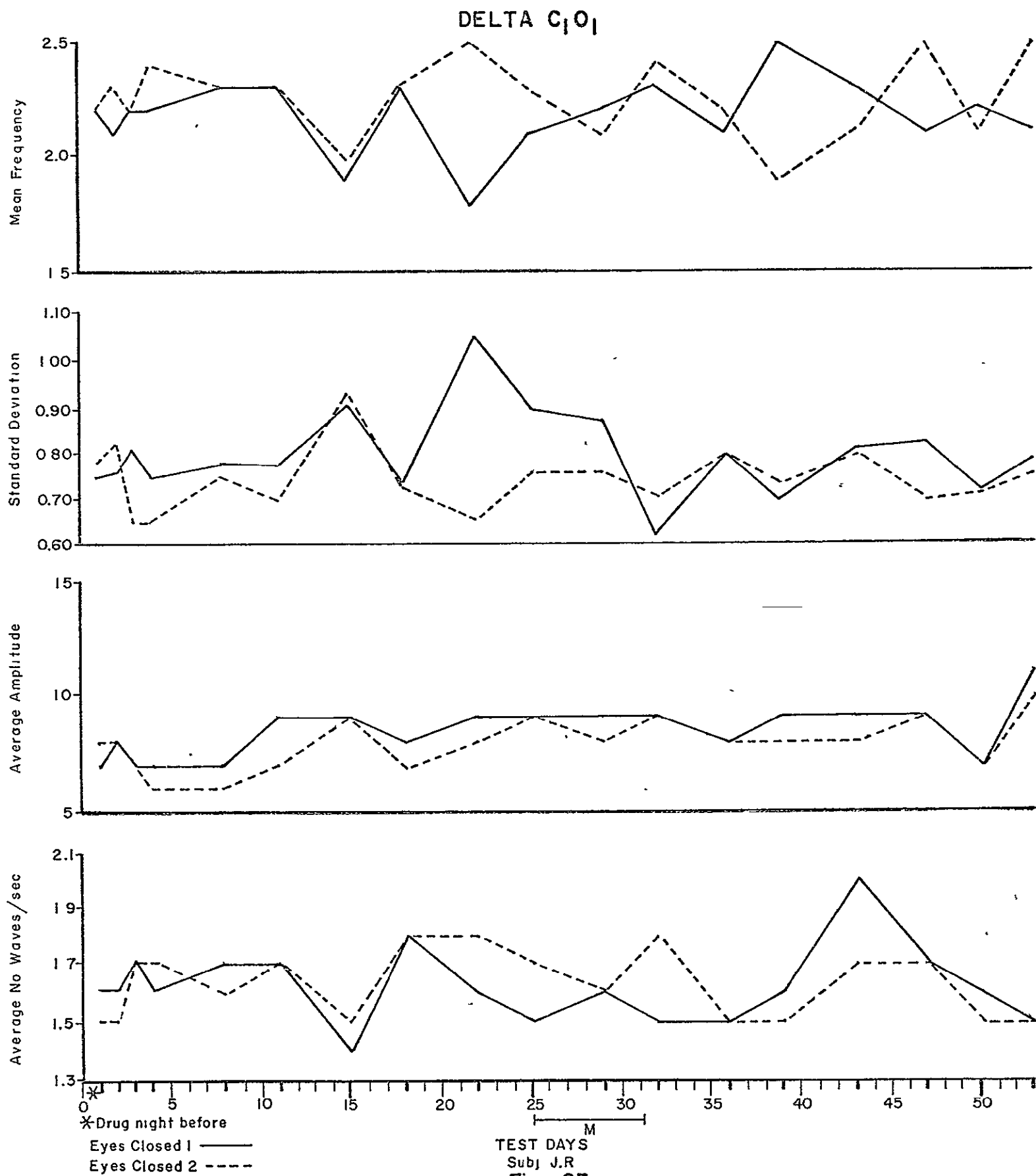
DELTA C₁O₁

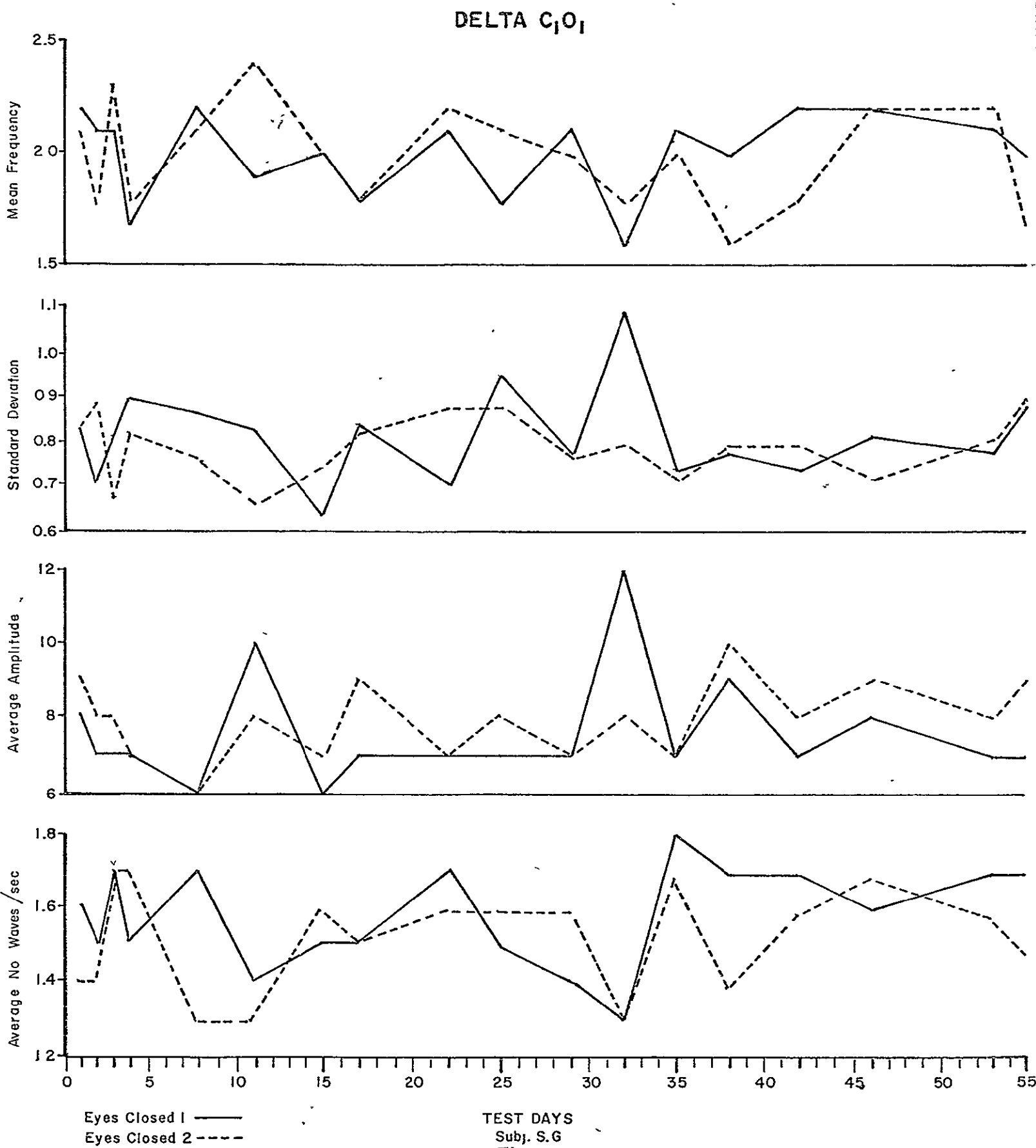


TEST DAYS
Subj E.B.
Fig. 21

DELTA C₁O₁

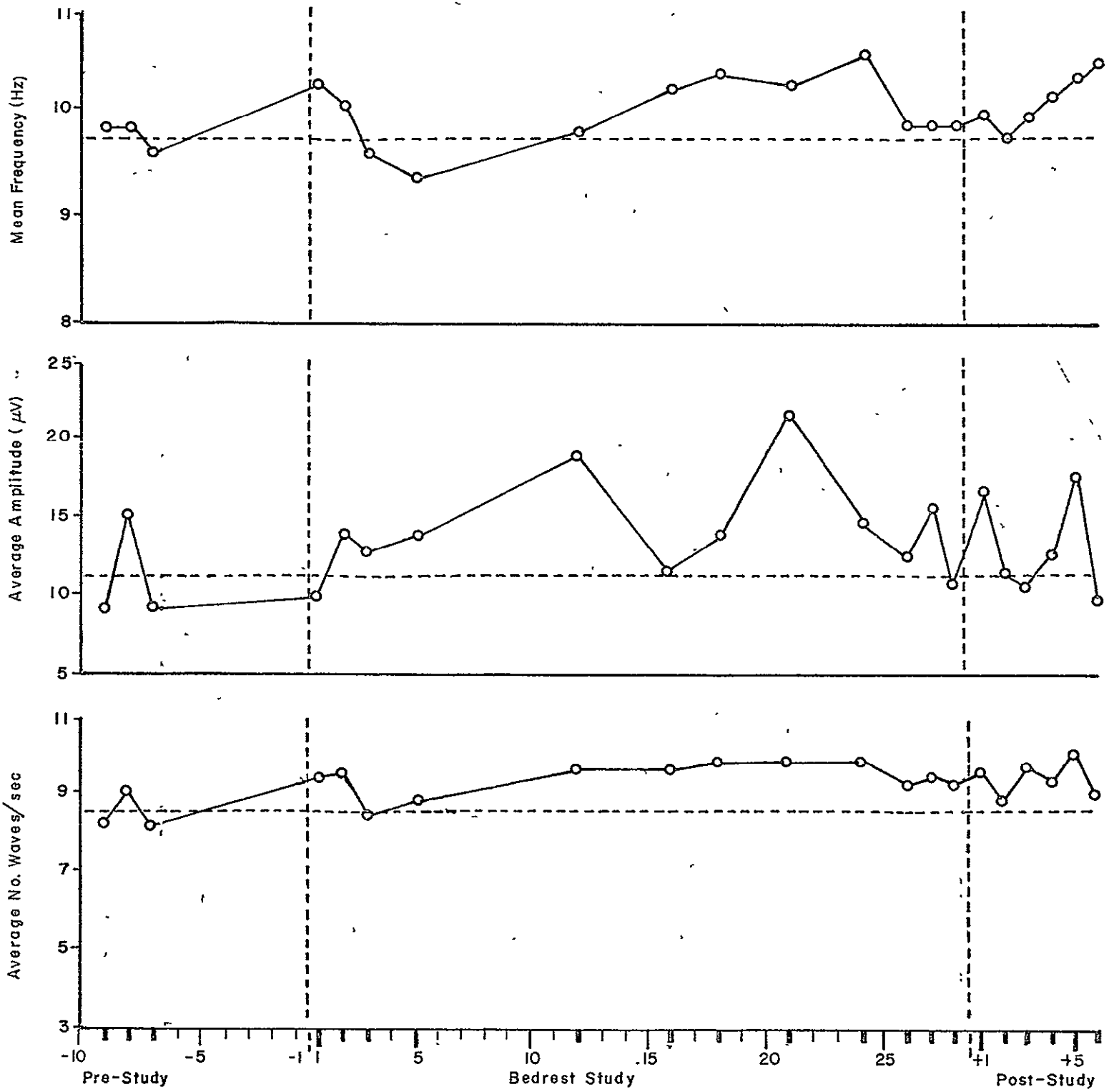






TEST DAYS
Subj. S.G
Fig. 24

Awake, Eyes Closed (I)
ALPHA C₁ O₁



TEST DAYS
Subj. J.H.
Fig. 25

Awake, Eyes Closed (I)
ALPHA C₁O₁

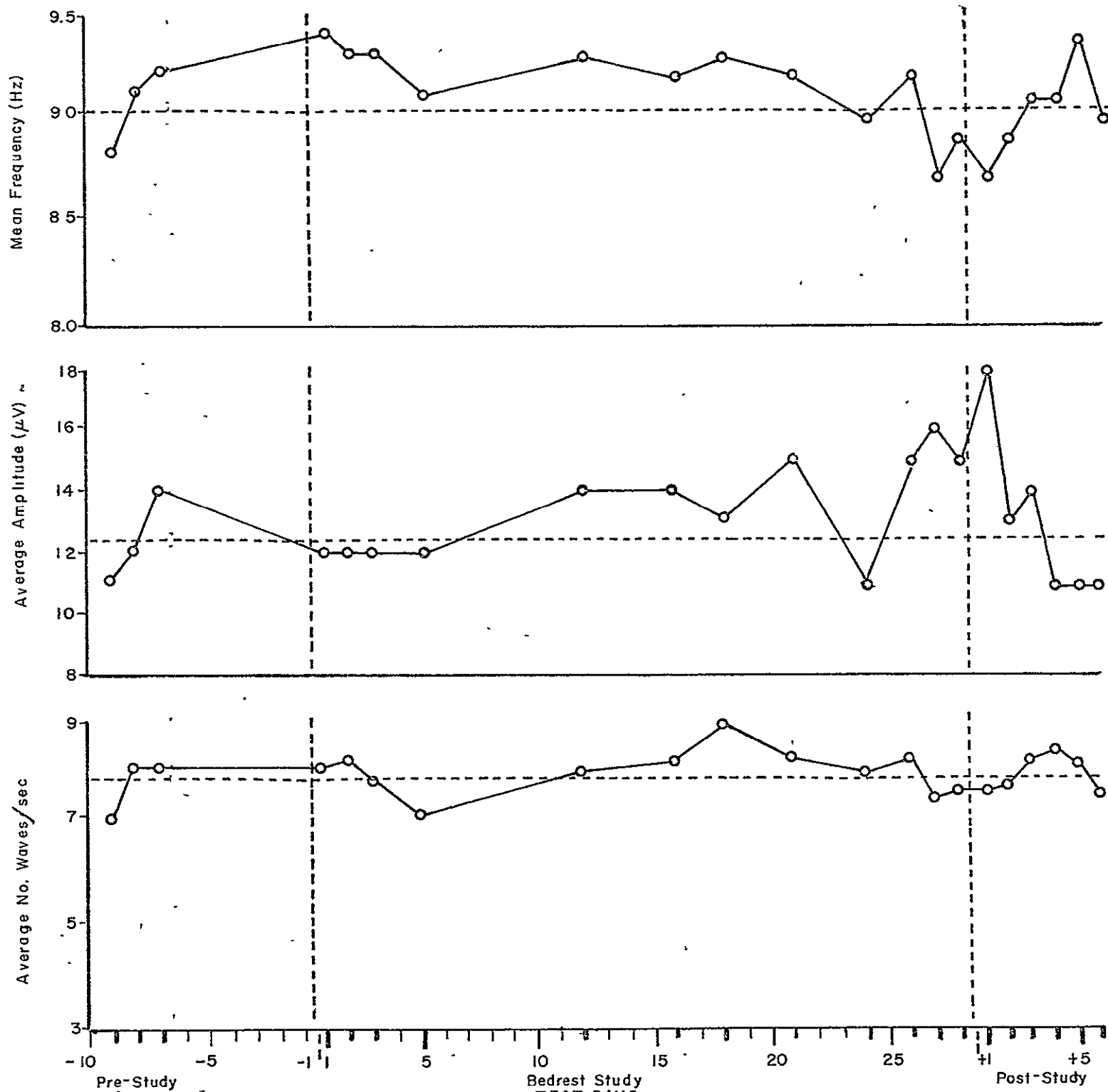
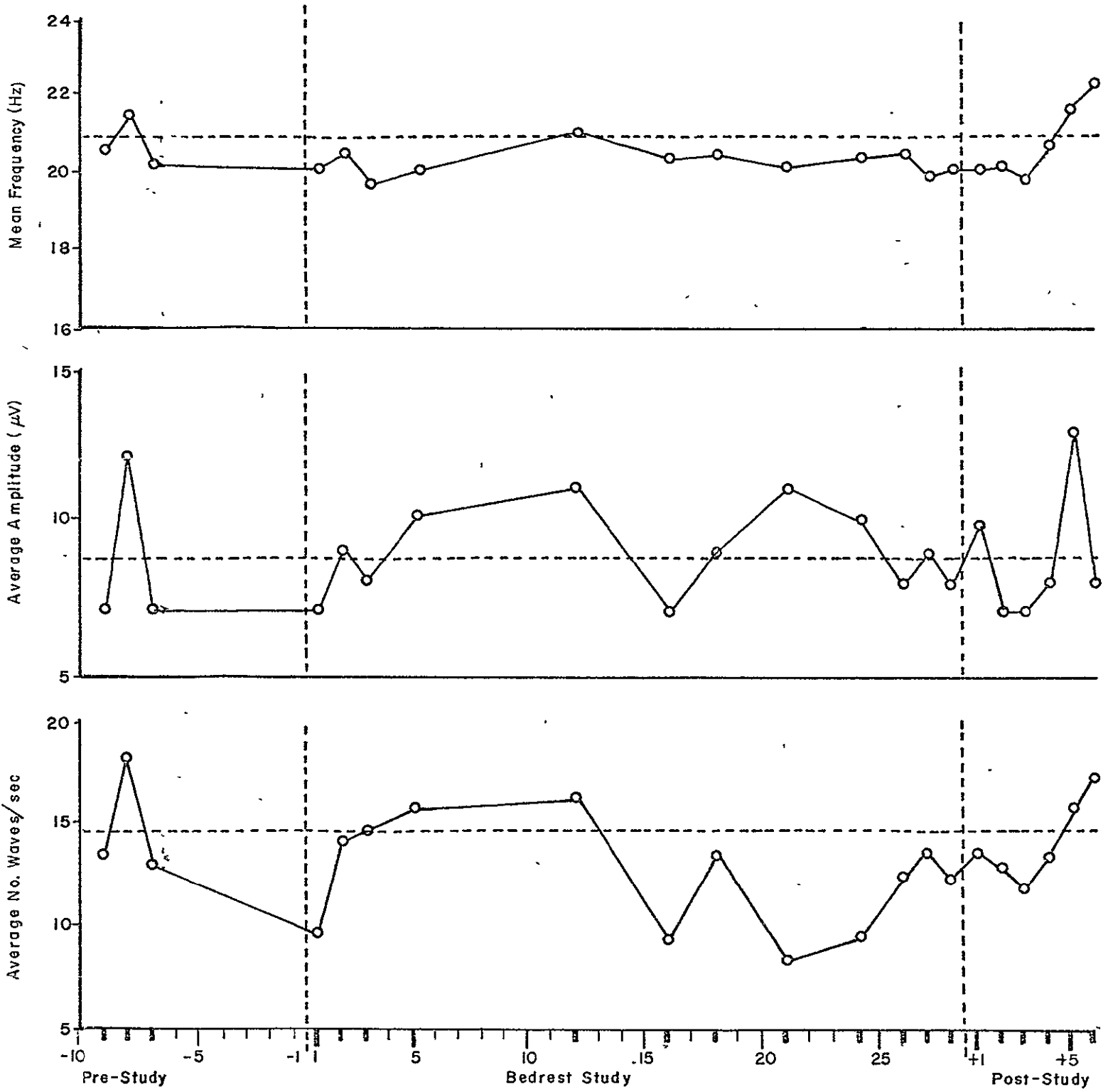


Fig. 26

Awake, Eyes Closed (I)
BETA C₁O₁



TEST DAYS
Subj. J H.
Fig. 27

Awake, Eyes Closed (I)
BETA C₁O₁

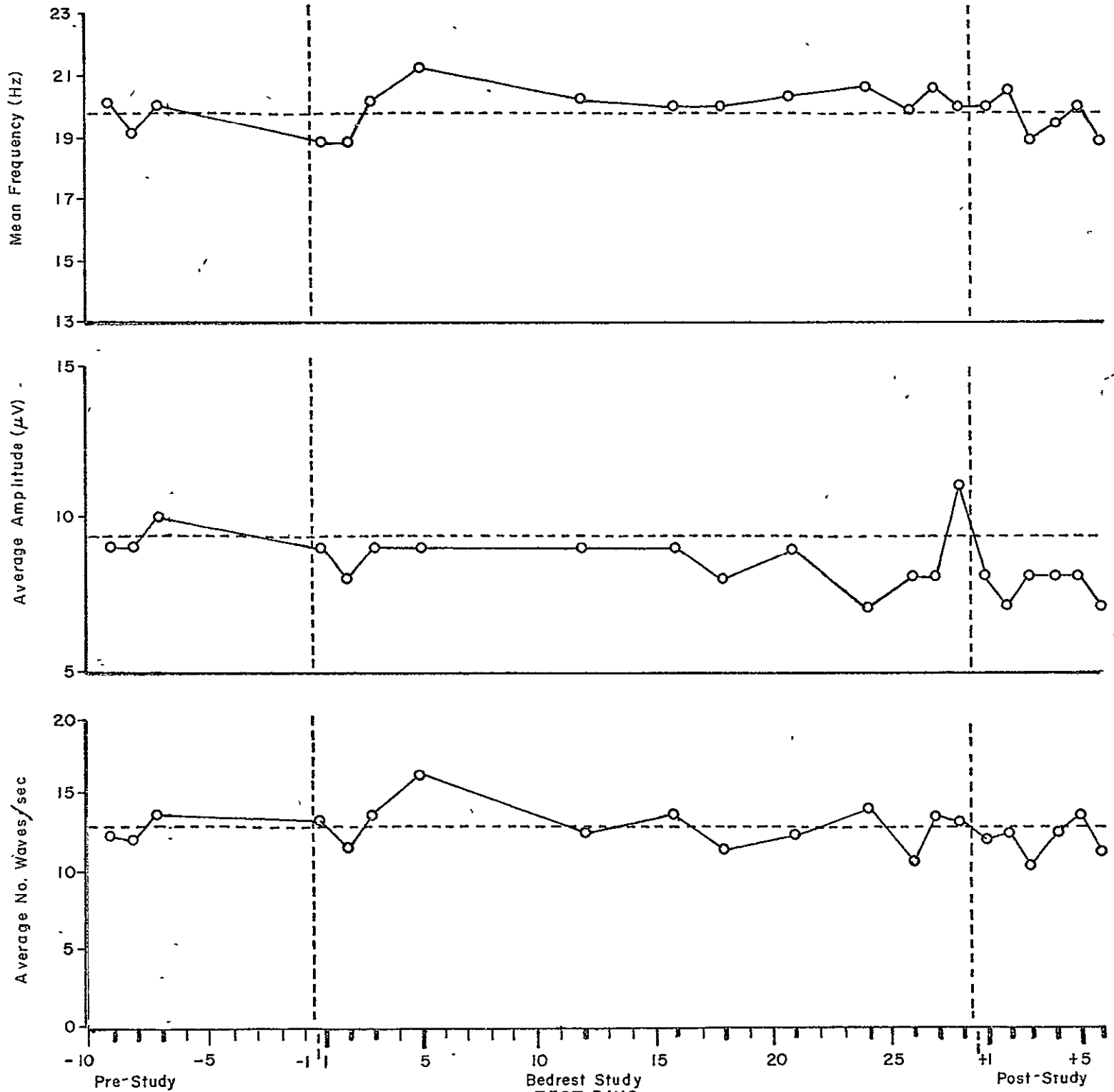
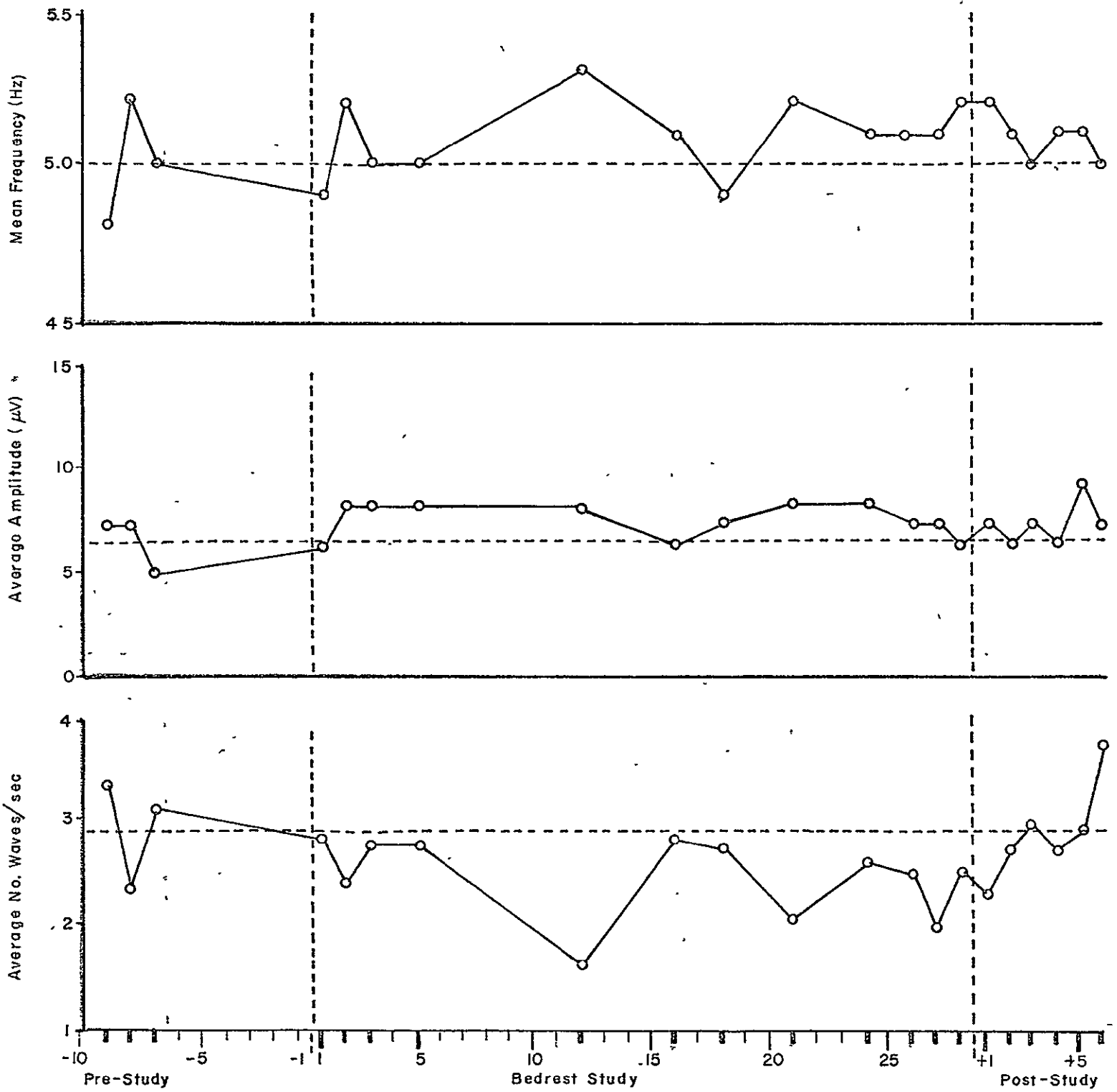
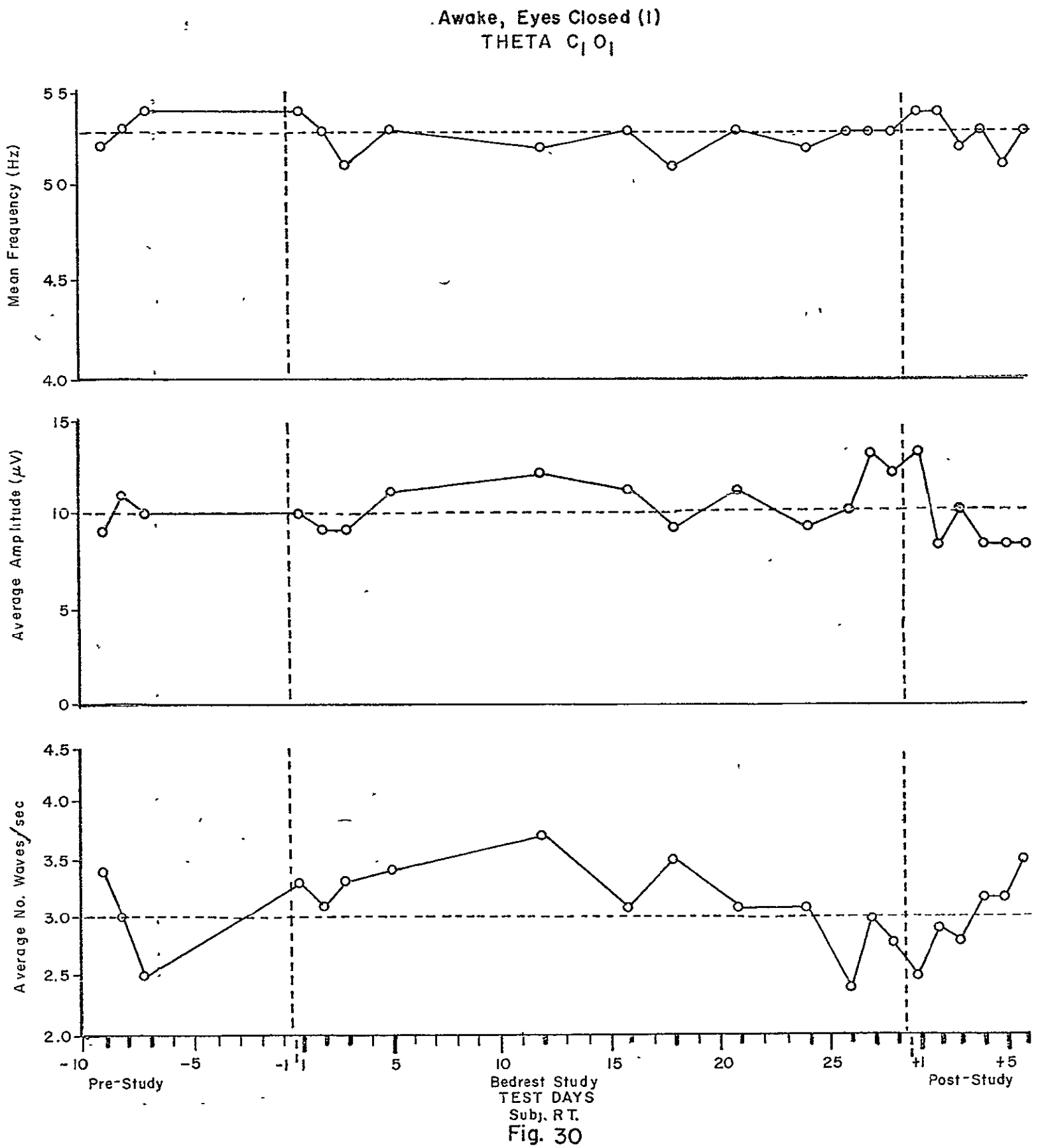


Fig. 28

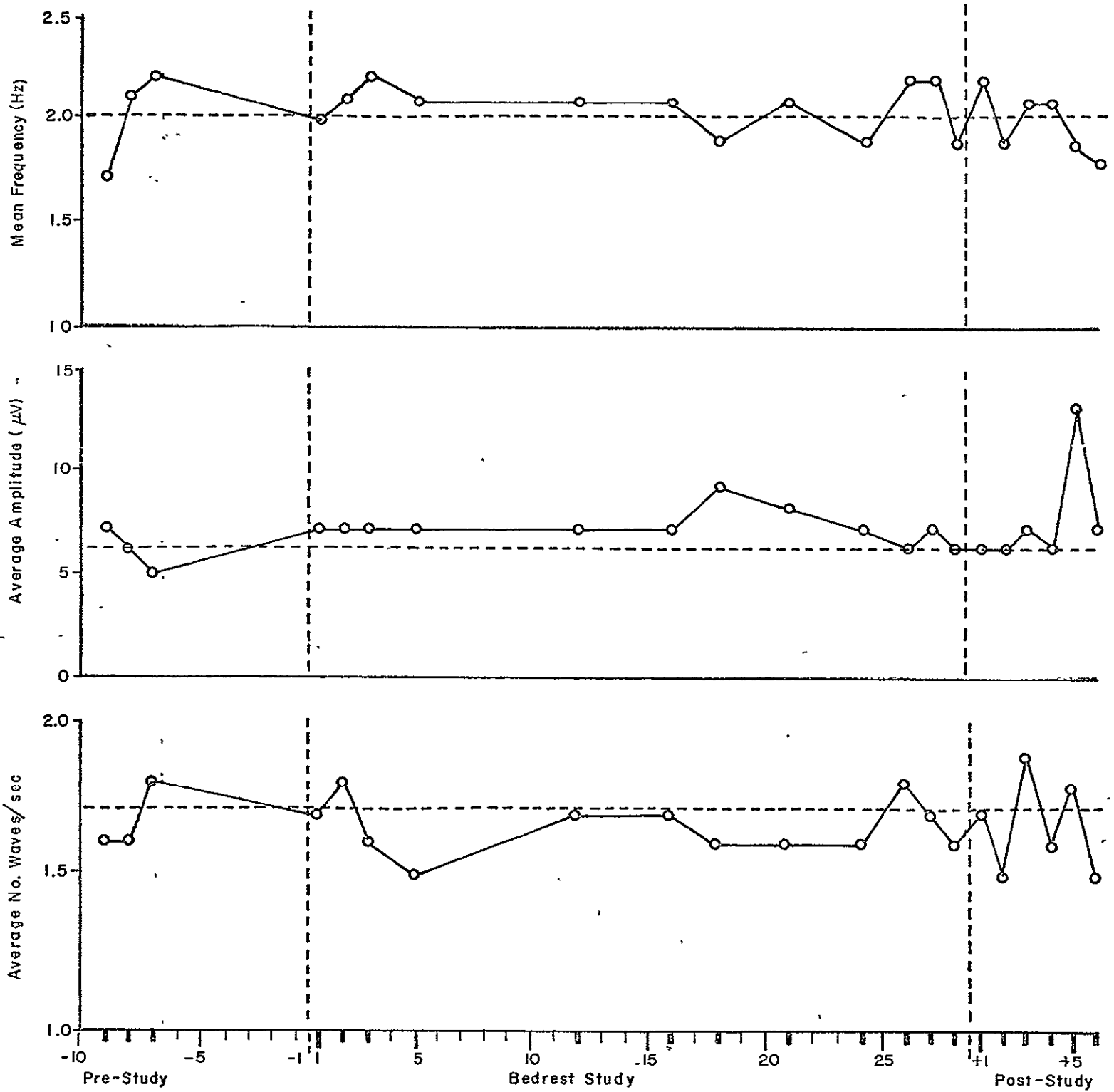
Awake, Eyes Closed (I)
THETA C₁O₁



TEST DAYS
Subj. J.H.
Fig. 29



Awake, Eyes Closed (I)
DELTA C₁O₁



TEST DAYS
Subj. J H.
Fig. 31

Awake, Eyes Closed (I)
DELTA C₁ O₁

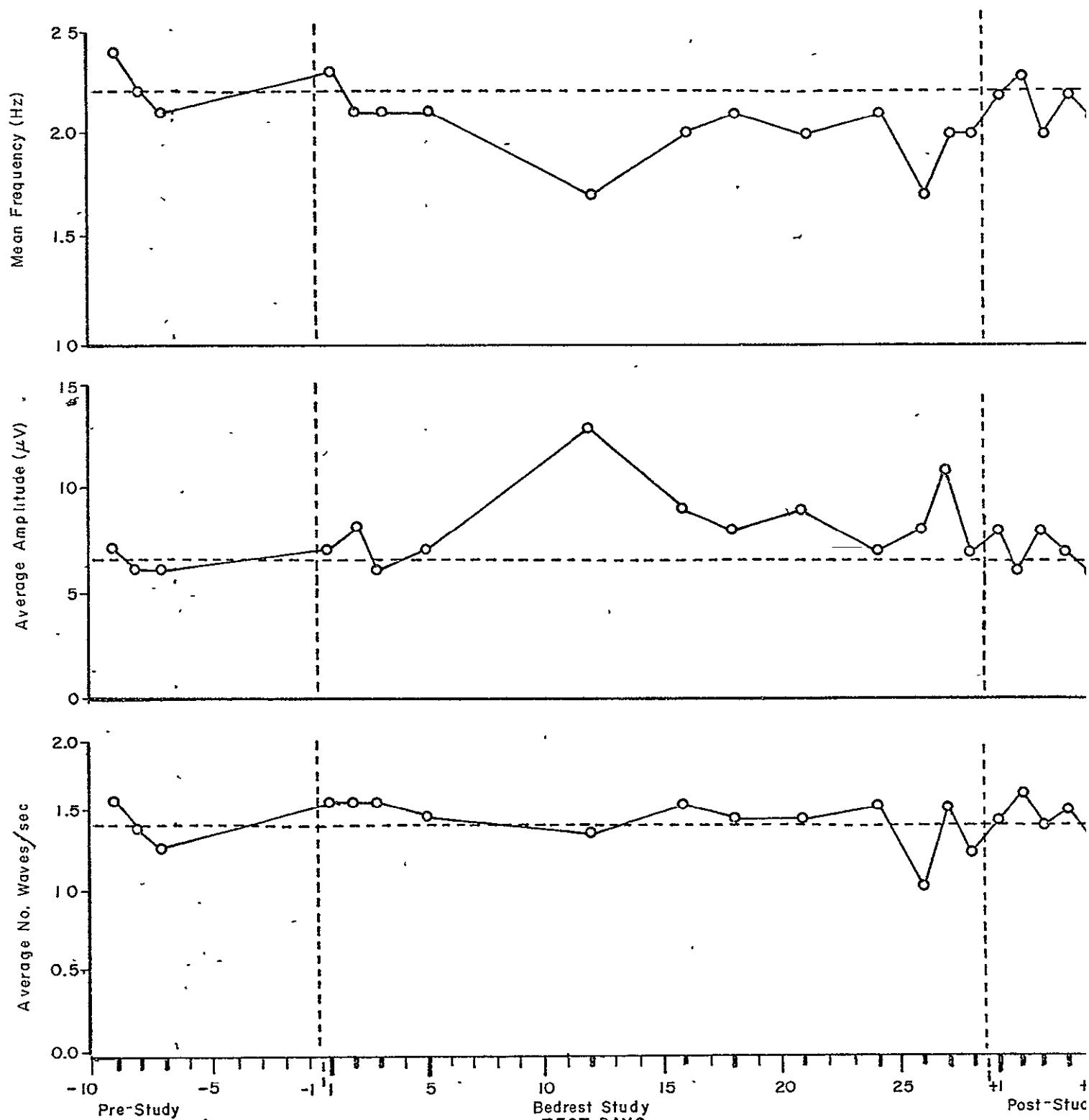


Fig. 32

MEAN FREQUENCY (Hz)	AVERAGE VALUE		STD DEV.		RANGE	
	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)
CH	10.1	10.0	0.15	0.13	0.5	0.4
GK	9.3	9.4	0.19	0.19	0.7	0.7
EB	9.5	9.9	0.31	0.38	1.0	1.3
CS	9.8	10.0	0.23	0.25	0.7	0.8
JR	9.6	9.5	0.27	0.30	1.0	1.1
SG	9.7	9.9	0.36	0.39	1.3	1.6
OVERALL AVERAGE	9.7	9.8	0.25	0.27	0.7	1.0

AVERAGE AMPLITUDE (μ V)						
CH	24.2	19.2	4.25	2.01	19.0	7.0
GK	21.3	24.9	3.56	4.81	13.0	19.0
EB	16.2	22.7	3.69	4.89	12.0	18.0
CS	8.7	9.2	1.56	2.12	6.0	9.0
JR	8.7	8.1	1.75	1.68	6.0	6.0
SG	10.3	11.3	2.95	3.25	12.0	14.0
OVERALL AVERAGE	14.9	15.9	2.96	3.13	11.3	12.2

NUMBER WAVES/SEC						
CH	9.9	9.6	0.18	0.19	0.5	0.7
GK	8.4	8.7	0.35	0.29	1.4	0.1
EB	8.5	9.1	0.36	0.43	1.3	1.5
CS	6.9	6.7	0.39	0.42	1.5	1.4
JR	7.0	6.7	0.65	0.72	2.8	2.8
SG	7.9	8.2	0.54	0.69	2.0	2.5
OVERALL AVERAGE	8.1	8.2	0.41	0.46	1.6	1.5

TABLE I. Average Values, Control Study, Eyes Closed (I), ALPHA Range, n=18

	AVERAGE VALUE		STD. DEV.		RANGE	
MEAN FREQUENCY (Hz)	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)
CH	19.7	20.0	0.41	0.59	1.8	2.3
GK	18.6	18.8	0.87	1.03	4.0	4.2
EB	19.2	19.4	0.65	0.65	2.1	2.4
CS	20.3	20.7	1.10	1.07	4.2	3.9
JR	20.6	20.9	0.68	1.12	2.9	4.5
SG	19.6	20.7	1.00	1.83	4.4	5.6
OVERALL AVERAGE	19.7	20.1	0.79	1.05	3.2	3.8

AVERAGE AMPLITUDE (μ V)						
CH	9.2	8.4	1.00	0.70	4.0	2.0
GK	7.8	8.4	0.99	1.24	3.0	4.0
EB	10.2	12.9	1.86	2.83	6.0	11.0
CS	10.3	11.6	1.67	2.38	6.0	9.0
JR	6.7	6.7	0.57	0.83	2.0	3.0
SG	8.6	9.6	1.29	1.61	5.0	6.0
OVERALL AVERAGE	8.8	9.6	1.23	1.60	4.3	5.8

NUMBER WAVES/SEC						
CH	5.9	8.5	1.57	1.81	6.4	7.2
GK	7.4	7.6	1.57	1.77	5.6	5.3
EB	13.0	11.9	1.74	2.12	6.8	6.9
CS	17.7	18.4	0.95	1.23	3.9	5.3
JR	15.2	15.7	1.75	2.11	6.8	9.0
SG	14.9	16.0	1.61	2.59	5.9	9.3
OVERALL AVERAGE	12.4	13.0	1.53	1.94	5.9	7.2

TABLE II. Average Values, Control Study, Eyes Closed (I), BETA Range, n=18

MEAN FREQUENCY (Hz)	AVERAGE VALUE		STD. DEV.		RANGE	
	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)
CH	5.0	5.0	0.10	0.10	0.3	0.4
GK	5.0	5.1	0.11	0.11	0.4	0.4
EB	5.0	5.1	0.12	0.14	0.4	0.5
CS	4.9	4.9	0.12	0.12	0.4	0.4
JR	4.9	4.9	0.12	0.13	0.4	0.5
SG	4.9	5.0	0.14	0.16	0.6	0.6
OVERALL AVERAGE	5.0	5.0	0.12	0.13	0.42	0.47

AVERAGE AMPLITUDE (μ V)						
CH	10.9	9.1	1.73	0.94	7.0	3.0
GK	10.4	10.2	2.81	2.71	10.0	9.0
EB	8.6	9.2	1.82	1.77	6.0	7.0
CS	6.3	6.2	0.57	0.65	2.0	3.0
JR	7.8	7.8	1.26	1.26	6.0	5.0
SG	6.8	6.9	1.04	1.08	3.0	3.0
OVERALL AVERAGE	8.5	8.2	1.54	1.40	5.7	4.2

NUMBER WAVES/SEC						
CH	2.4	2.7	0.36	0.29	1.3	0.9
GK	2.3	2.0	0.36	0.33	1.3	1.3
EB	2.6	2.3	0.26	0.26	1.1	0.9
CS	3.1	3.1	0.27	0.20	0.9	0.7
JR	3.4	3.6	0.17	0.24	0.8	0.9
SG	3.0	3.0	0.28	0.37	1.3	1.5
OVERALL AVERAGE	2.8	2.8	0.28	0.28	1.1	1.0

TABLE III. Average Values, Control Study, Eyes Closed (1), THETA Range, n=18

MEAN FREQUENCY (Hz)	AVERAGE VALUE		STD. DEV.		RANGE	
	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)	C ₁ O ₁ (LEFT)	C ₂ O ₂ (RIGHT)
CH	2.4	2.4	0.19	0.11	0.6	0.4
GK	2.3	2.3	0.18	0.14	0.6	0.5
EB	2.2	2.3	0.17	0.13	0.6	0.4
CS	1.8	1.9	0.17	0.10	0.7	0.3
JR	2.2	2.2	0.16	0.16	0.7	0.7
SG	2.0	2.1	0.18	0.17	0.6	0.6
OVERALL AVERAGE	2.2	2.2	0.18	0.14	0.6	0.5

AVERAGE AMPLITUDE (μ V)						
CH	8.2	7.3	0.79	0.84	2.0	3.0
GK	7.6	7.7	1.65	1.24	7.0	4.0
EB	7.5	8.1	1.79	1.35	8.0	6.0
CS	8.4	7.9	1.09	0.83	4.0	3.0
JR	8.4	8.3	1.09	1.13	4.0	5.0
SG	7.6	7.0	1.46	0.69	6.0	2.0
OVERALL AVERAGE	8.0	7.7	1.31	1.01	5.2	3.8

NUMBER WAVES/SEC						
CH	1.3	1.6	0.13	0.14	0.4	0.4
GK	1.5	1.6	0.23	0.17	1.1	0.6
EB	1.4	1.7	0.30	0.16	1.2	0.7
CS	1.5	1.7	0.10	0.09	0.4	0.3
JR	1.6	1.7	0.14	0.12	0.6	0.4
SG	1.6	1.7	0.14	0.11	0.5	0.4
OVERALL AVERAGE	1.5	1.7	0.17	0.13	0.7	0.5

TABLE IV. Average Values, Control Study, Eyes Closed (I), DELTA Range, n=18

Average Values, Bedrest Study, Awake Eyes Closed (I)

MEAN FREQ. (Hz)	AVERAGE VALUE			STANDARD DEV.			RANGE		
	Pre-Study n=3	Bedrest n=12	Post-Study n=6	Pre-Study n=3	Bedrest n=12	Post-Study n=6	Pre-Study n=3	Bedrest n=12	Post-Study n=6
JH	9.7	10.0	10.1*	0.12	0.35	0.35	0.2	1.2	1.0
RT	9.0	9.2	9.0	0.21	0.20	0.23	0.4	0.7	0.7
OVERALL AVERAGE	9.4	9.6	9.6	0.17	0.28	0.29	0.3	1.0	0.9

AVERAGE AMPLITUDE									
JH	11.0	14.4	13.5	3.46	3.34	3.27	6.0	12.0	8.0
RT	12.3	13.4	13.0	1.53	1.62	2.76	3.0	5.0	7.0
OVERALL AVERAGE	11.7	13.9	13.3	2.50	2.48	3.02	4.5	8.5	7.5

NUMBER WAVES/SEC									
JH	8.5	9.5**	9.6*	0.46	0.46	0.47	0.8	1.5	1.4
RT	7.7	8.0	8.0	0.58	0.47	0.38	1.0	1.9	1.0
OVERALL AVERAGE	8.1	8.8	8.8	0.52	0.47	0.43	0.9	1.7	1.2

*p≤0.05

**p≤0.02

Channel C1-O1, ALPHA Range, n=18

TABLE V

Average Values, Bedrest Study, Awake Eyes Closed (I)

MEAN FREQ. (Hz)	AVERAGE VALUE			STANDARD DEV.			RANGE		
	Pre-Study n=3	Bedrest n=12	Post-Study n=6	Pre-Study n=3	Bedrest n=12	Post-Study n=6	Pre-Study n=3	Bedrest n=12	Post-Study n=6
JH	20.8	20.3	20.9	0.74	0.31	1.02	1.4	0.7	2.4
RT	19.8	20.1	19.4	0.57	0.48	0.59	1.1	1.8	1.4
OVERALL AVERAGE	20.3	20.2	20.2	0.66	0.40	0.81	1.3	1.3	1.9

AVERAGE AMPLITUDE									
JH	8.7	8.9	8.8	2.89	1.38	2.32	5.0	4.0	6.0
RT	9.3	8.7	7.7**	0.58	0.98	0.52	1.0	4.0	1.0
OVERALL AVERAGE	9.0	8.8	8.3	1.74	1.18	1.42	3.0	4.0	3.5

NUMBER WAVES/SEC									
JH	14.7	12.4	14.1	3.06	2.57	2.05	5.3	7.8	5.5
RT	12.8	13.1	12.2	0.95	1.38	1.09	1.8	5.5	3.1
OVERALL AVERAGE	13.8	12.8	13.2	2.01	1.98	1.57	3.6	6.7	4.3

**p≤0.02

Channel C₁-O₁, BETA Range, n=18

TABLE VI

Average Values, Bedrest Study, Awake Eyes Closed (I)

MEAN FREQ. (Hz)	AVERAGE VALUE			STANDARD DEV.			RANGE		
	Pre-Study n=3	Bedrest n=12	Post-Study n=6	Pre-Study n=3	Bedrest n=12	Post-Study n=6	Pre-Study n=3	Bedrest n=12	Post-Study n=6
JH	5.0	5.1	5.1	0.20	0.12	0.08	0.4	0.4	0.2
RT	5.3	5.3	5.3	0.10	0.09	0.12	0.2	0.3	0.3
OVERALL AVERAGE	5.2	5.2	5.2	0.15	0.11	0.10	0.3	0.4	0.3

AVERAGE AMPLITUDE									
JH	6.3	7.3	7.0	1.15	0.87	0.10	2.0	2.0	3.0
RT	10.0	10.5	9.2	1.00	1.38	2.04	2.0	4.0	5.0
OVERALL AVERAGE	8.2	8.9	8.1	1.08	1.13	1.57	2.0	3.0	4.0

NUMBER WAVES/SEC									
JH	2.9	2.5	2.9	0.53	0.37	0.50	1.0	1.2	1.5
RT	3.0	3.2	3.0	0.45	0.34	0.35	0.9	1.3	1.0
OVERALL AVERAGE	3.0	2.9	3.0	0.49	0.36	0.43	1.0	1.3	1.3

Channel C₁-O₁, THETA Range, n=18

TABLE VII

Average Values, Bedrest Study, Awake Eyes Closed (I)

MEAN FREQ. (Hz)	AVERAGE VALUE			STANDARD DEV.			RANGE		
	Pre-Study n=3	Bedrest n=12	Post-Study n=6	Pre-Study n=3	Bedrest n=12	Post-Study n=6	Pre-Study n=3	Bedrest n=12	Post-Study n=6
JH	2.0	2.1	2.0	0.26	0.12	0.15	0.5	0.3	0.4
RT	2.2	2.0	2.2	0.15	0.17	0.10	0.3	0.6	0.3
OVERALL AVERAGE	2.1	2.1	2.1	0.21	0.15	0.13	0.4	0.5	0.4

AVERAGE AMPLITUDE									
JH	6.0	7.1	7.5	1.00	0.79	2.74	2.0	3.0	7.0
RT	6.3	8.3*	6.8	0.58	1.97	0.98	1.0	7.0	2.0
OVERALL AVERAGE	6.2	7.7	7.2	0.79	1.38	1.86	1.5	5.0	4.5

NUMBER WAVES / SEC									
JH	1.7	1.7	1.7	0.12	0.09	0.16	0.2	0.3	0.4
RT	1.4	1.5	1.6	0.15	0.16	0.12	0.3	0.5	0.3
OVERALL AVERAGE	1.6	1.6	1.7	0.14	0.13	0.14	0.3	0.4	0.4

*p≤0.05

Channel C₁-O₁, DELTA Range, n=18

TABLE VIII